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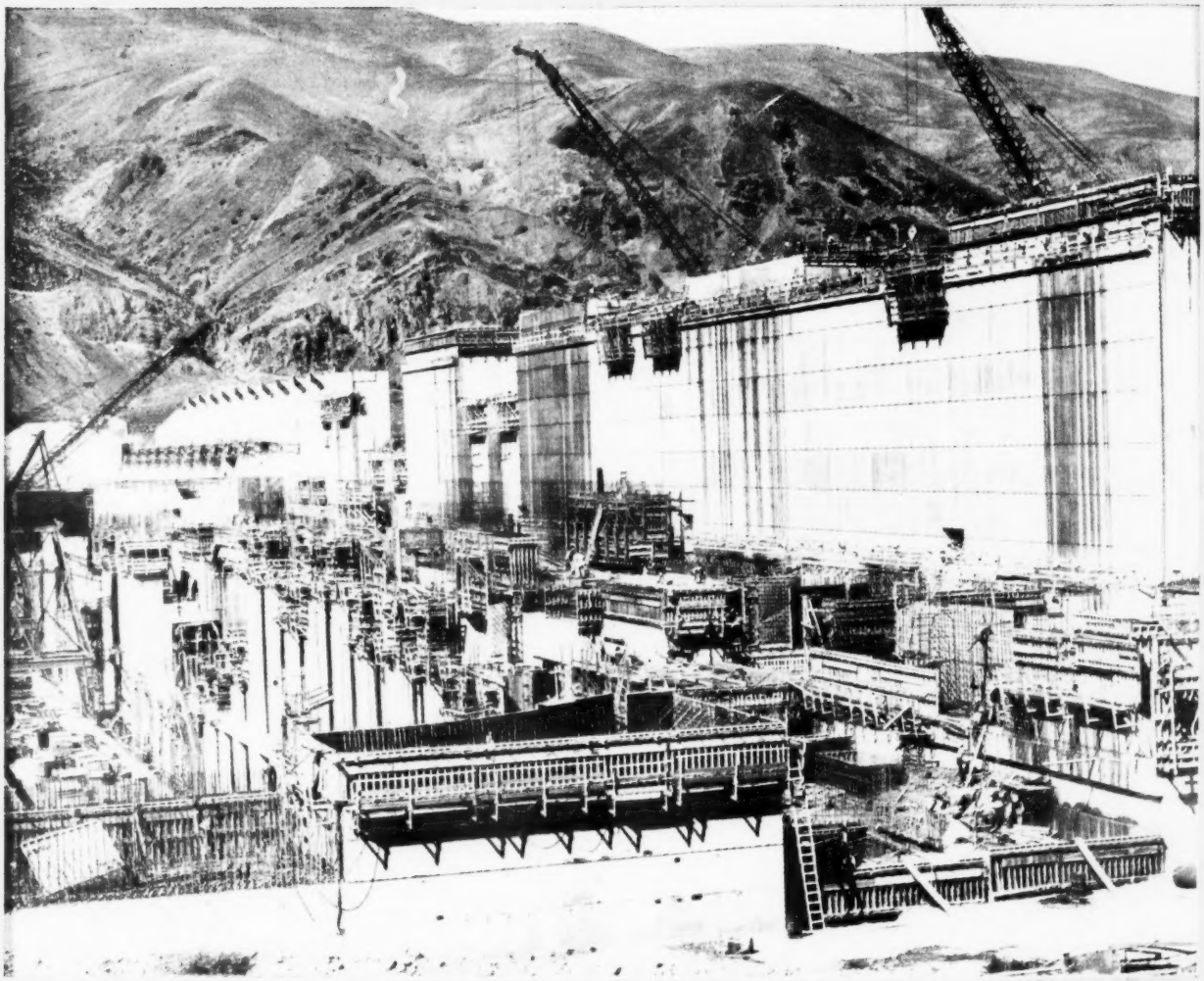

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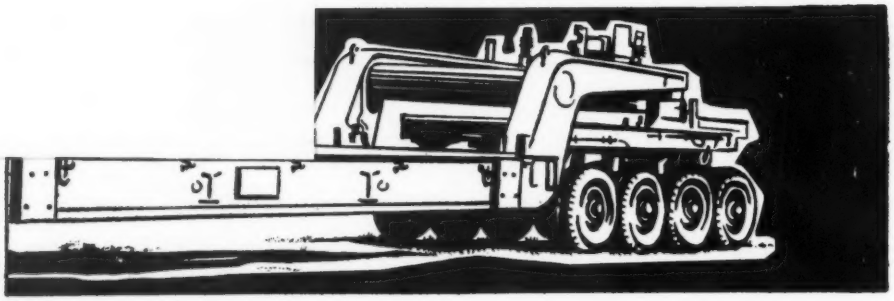

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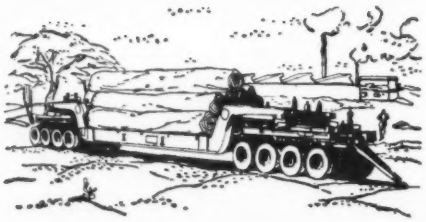

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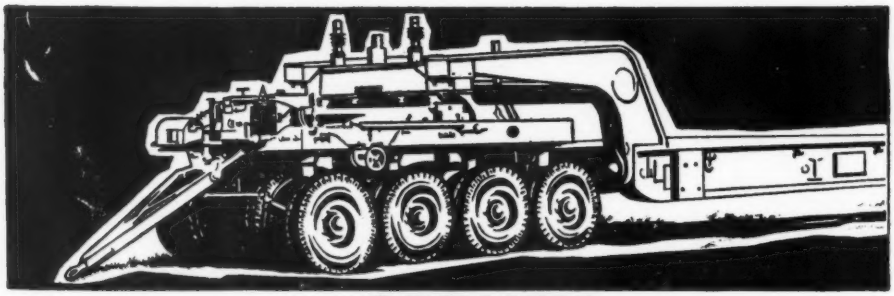

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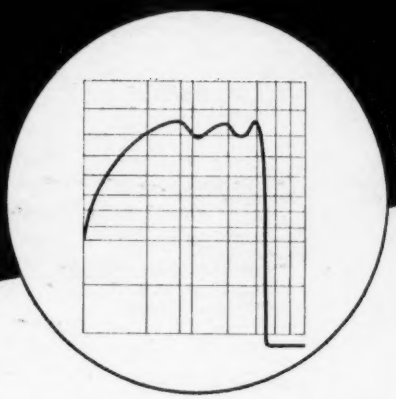

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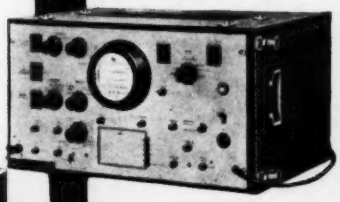

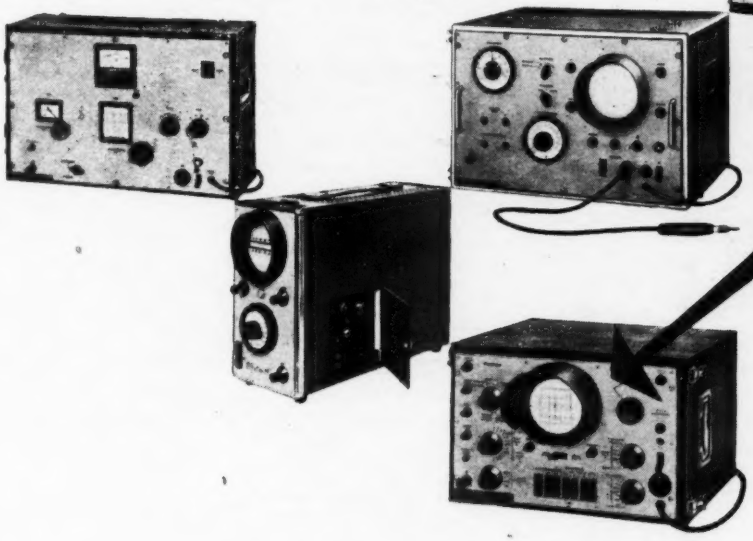

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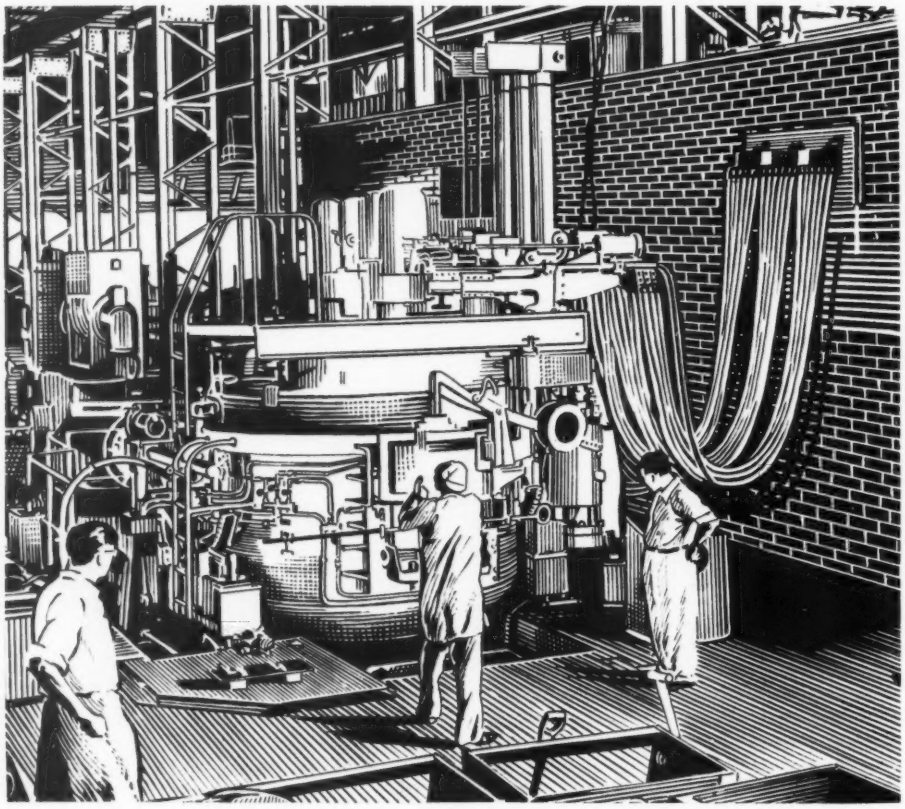

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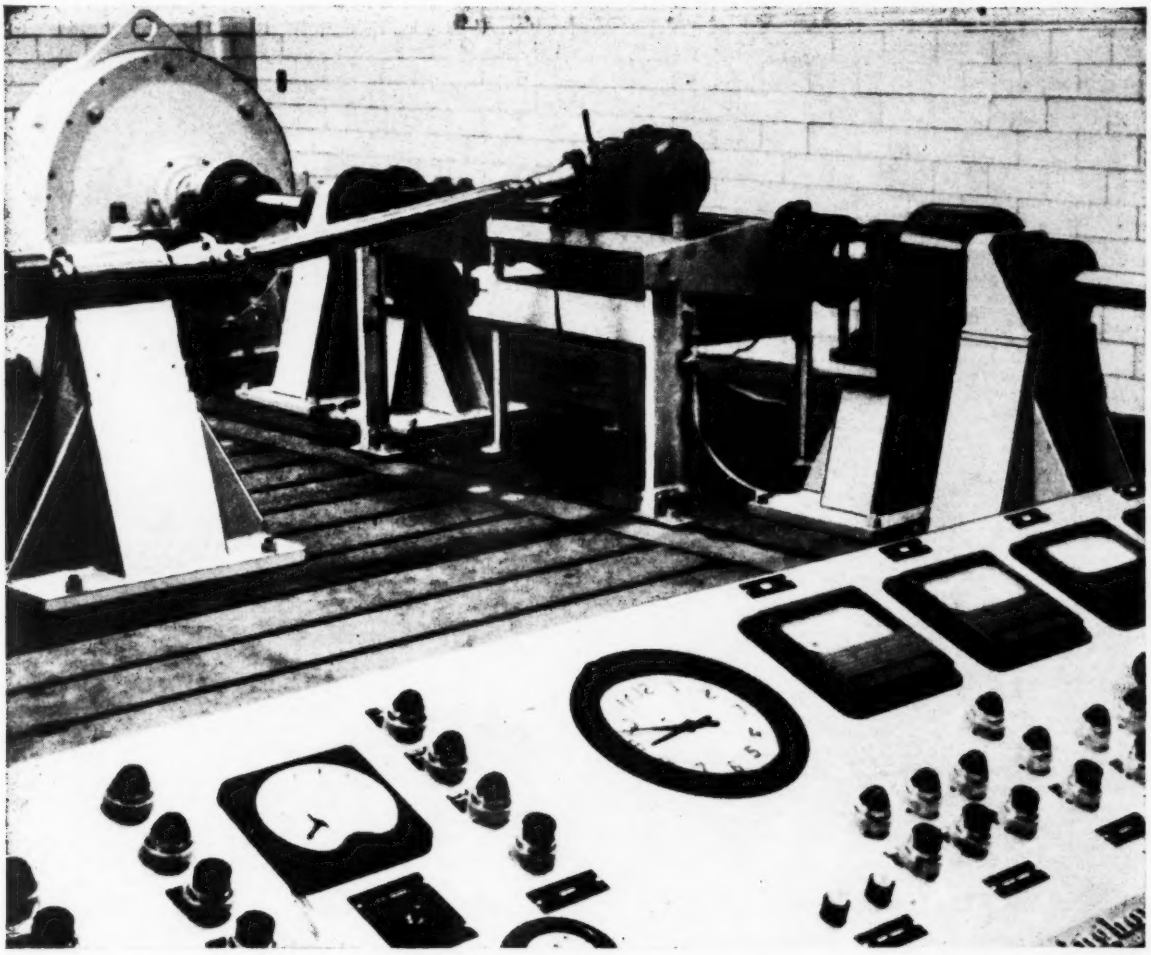

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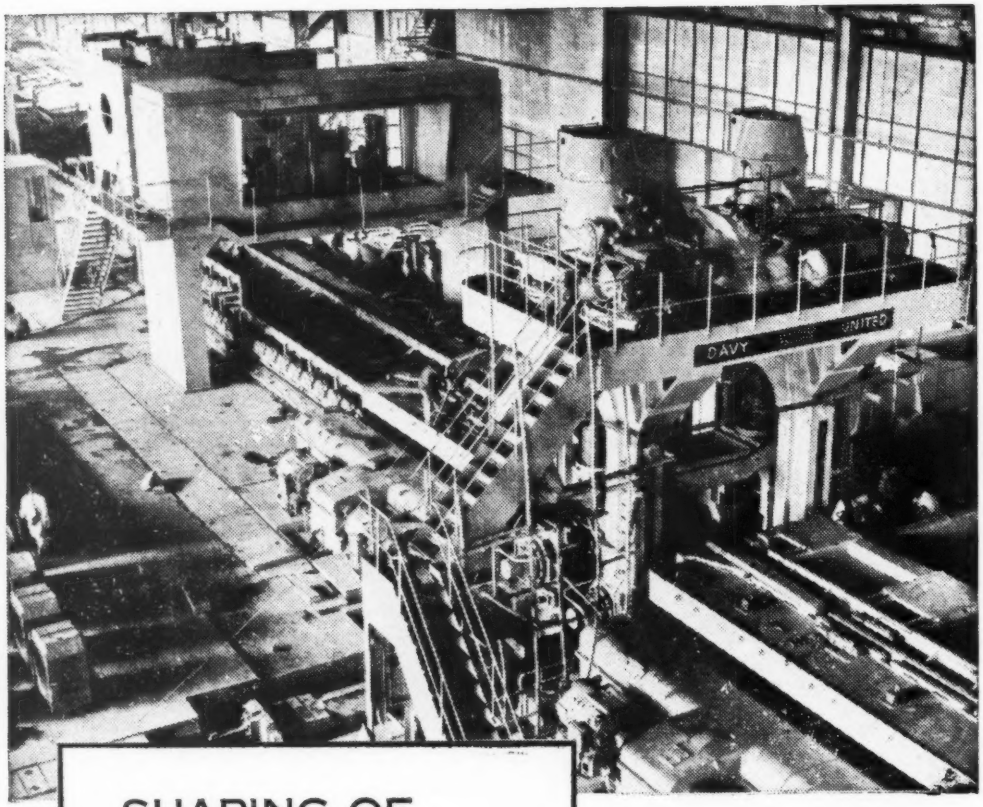

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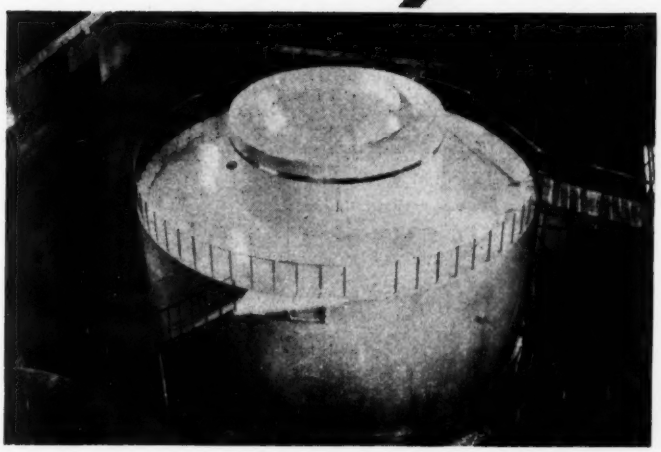

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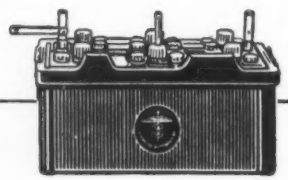

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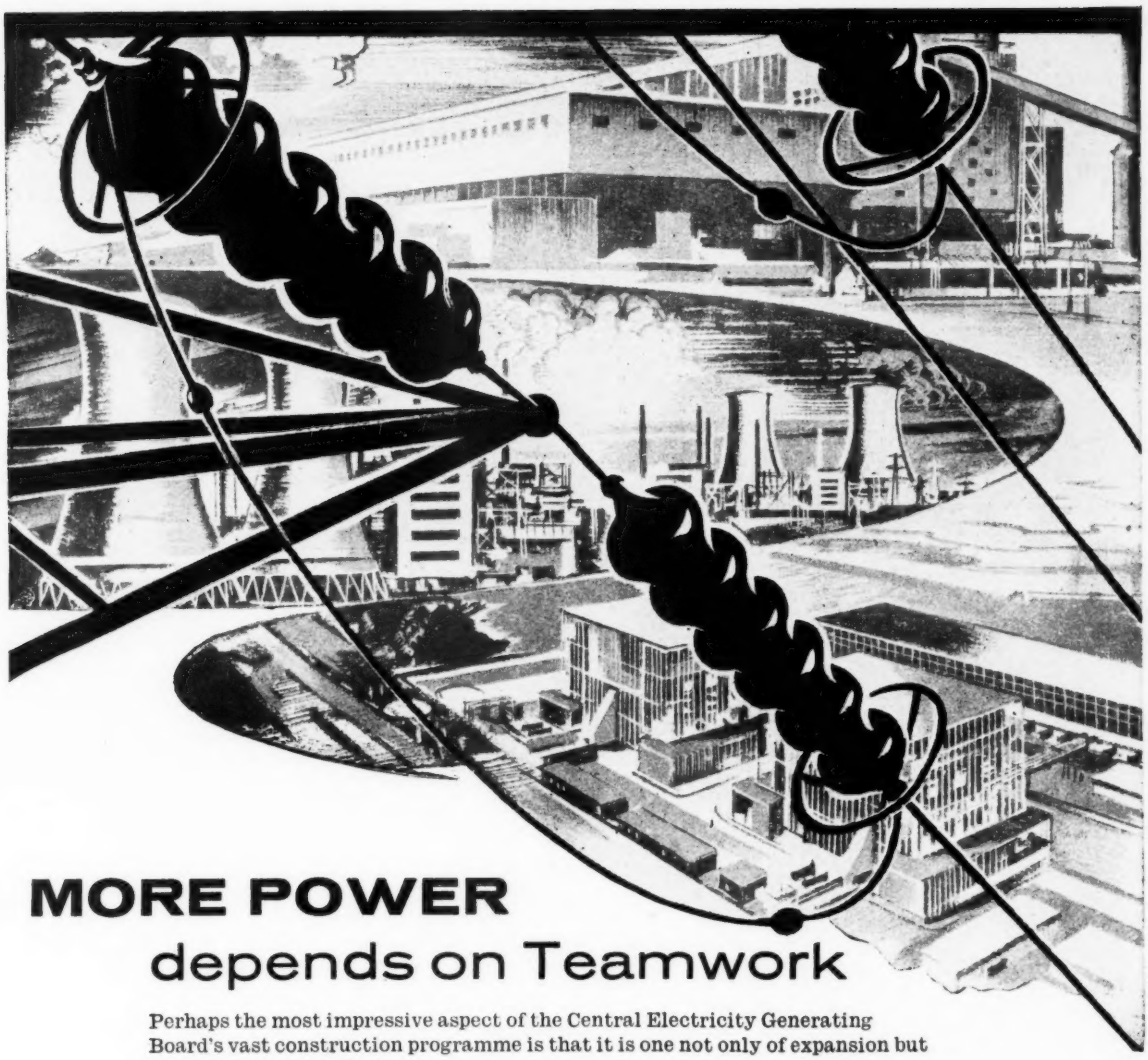

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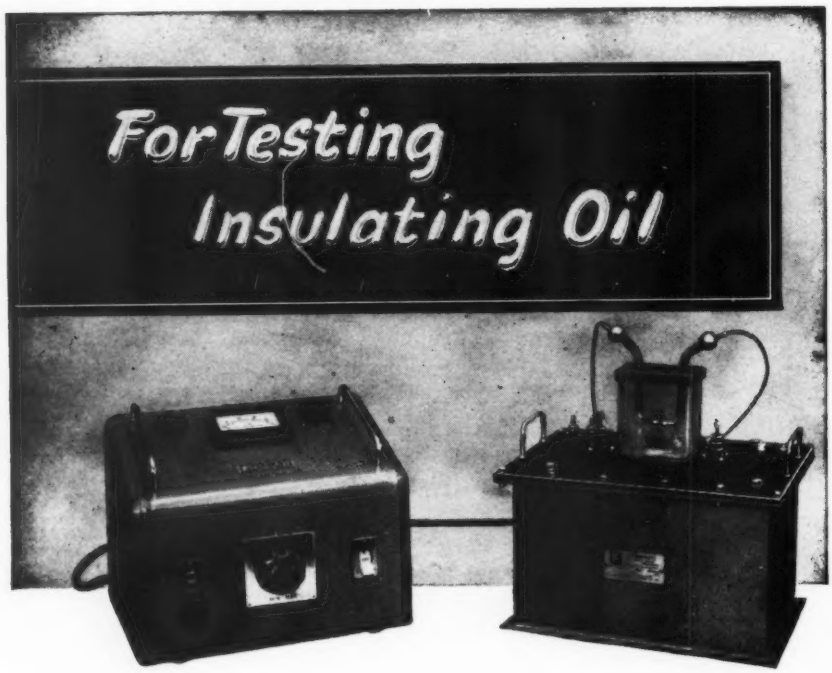

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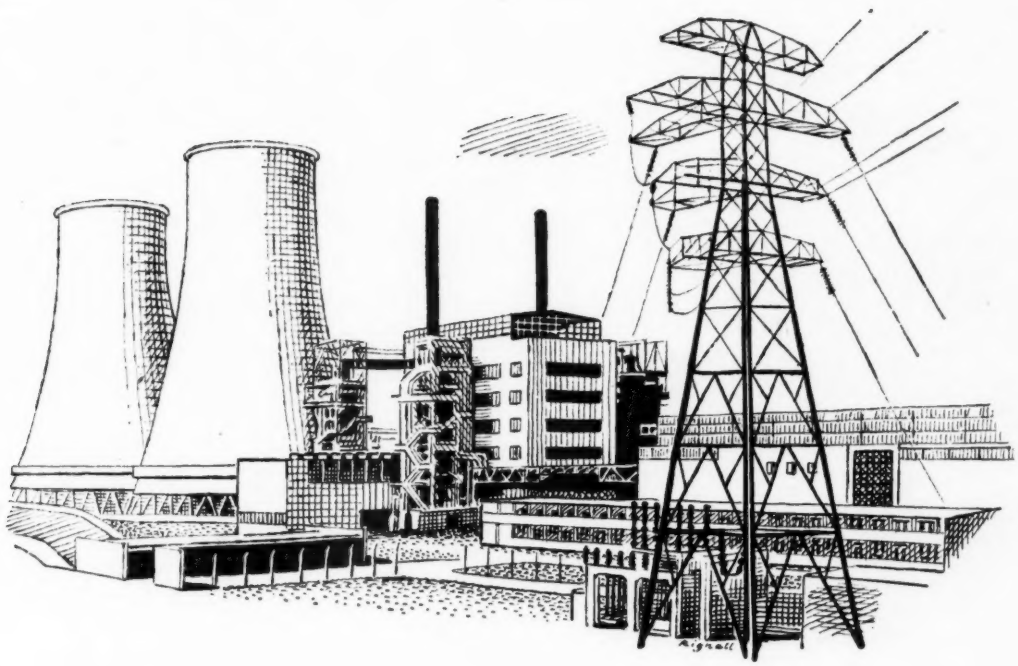

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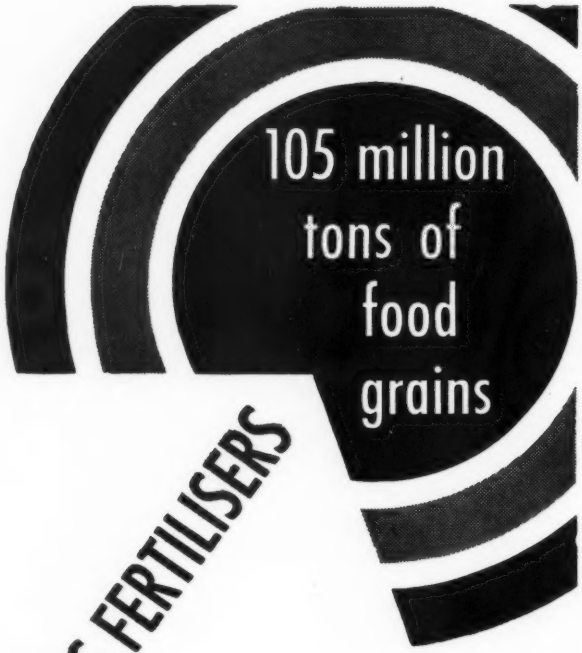

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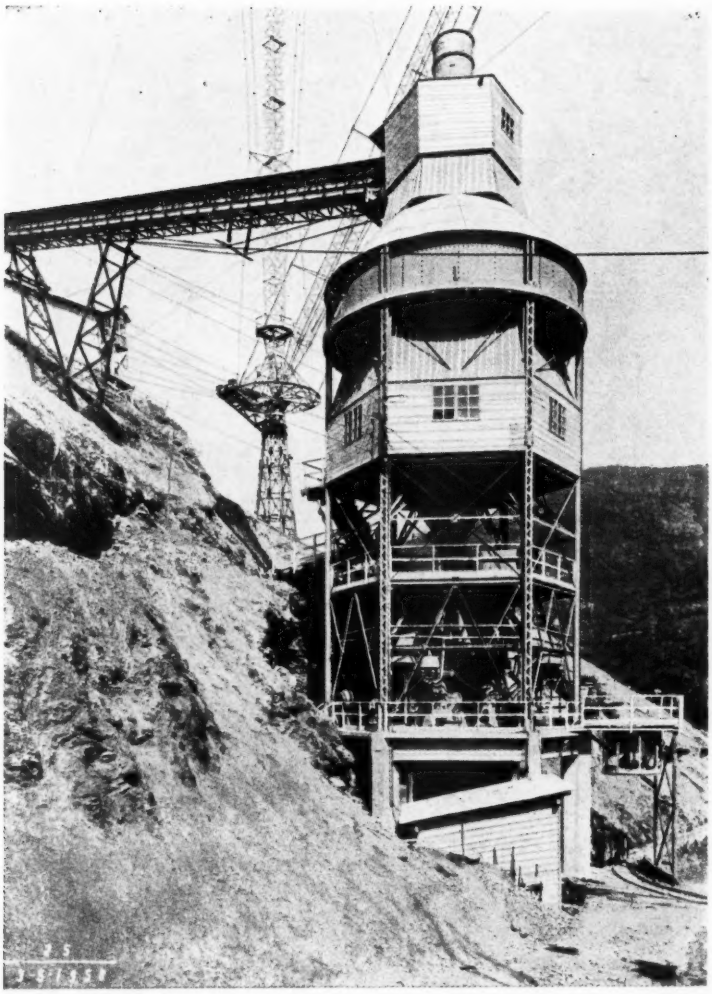

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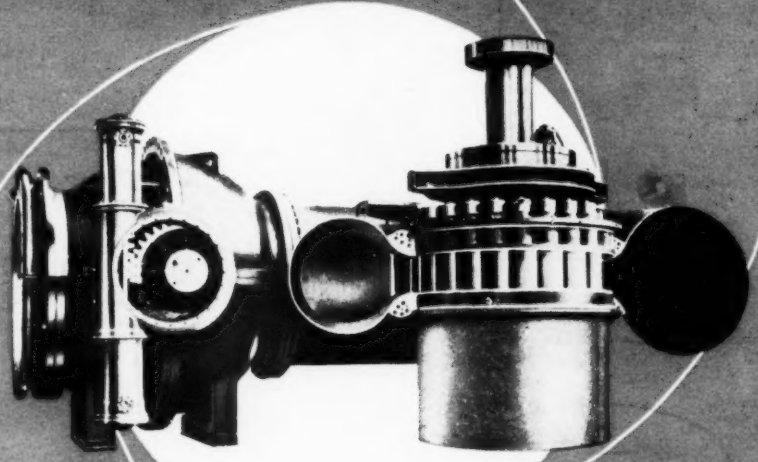

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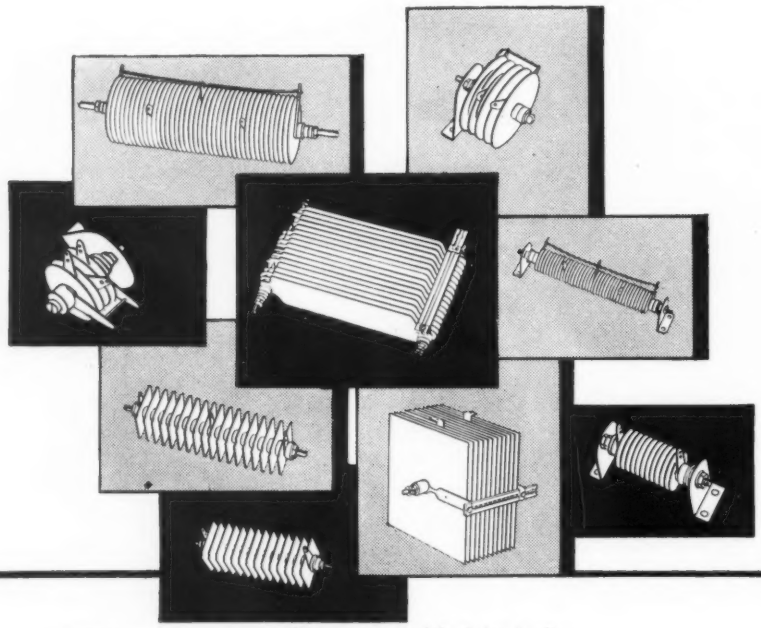

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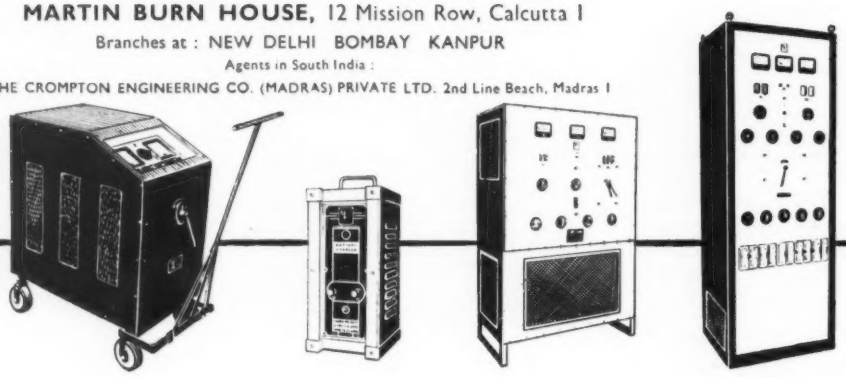

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A MONTHLY DEVOTED TO DEVELOPMENT OF POWER & WATER RESOURCES IN ASIA

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VOL. X — **MAY 1960** — **NO. 5**

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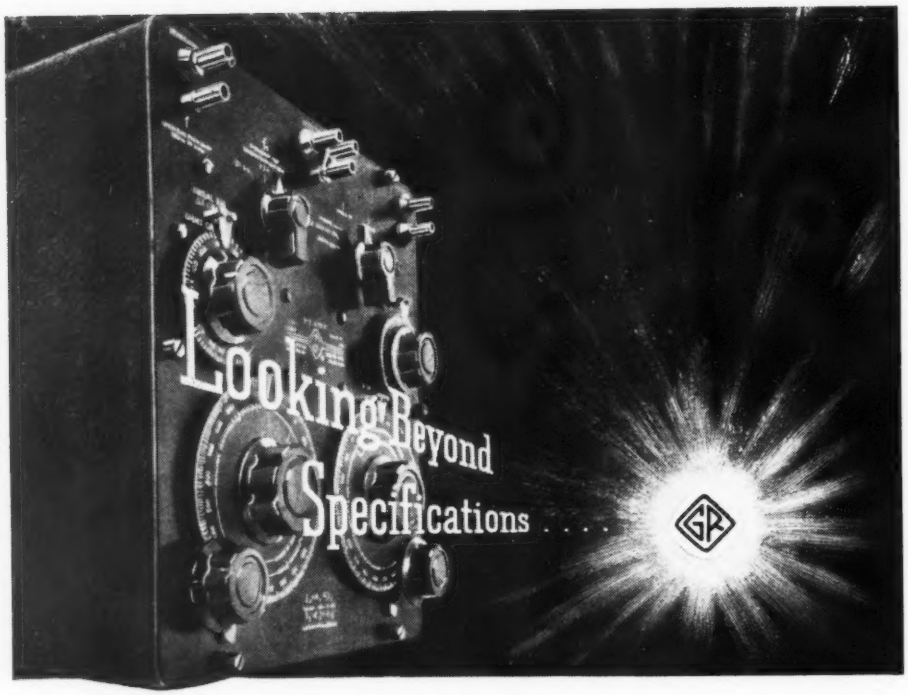

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Introduction

There is little doubt that British electrical industry occupies a leading position in the world in its field. Since the Second World War some significant technological developments in the generation of power has taken place and British contribution to it has been considerable.

To take only one instance, the large-scale programme of nuclear power that Britain has undertaken constitutes a magnificent advance and this would not have been possible without the tremendous effort in research put in by U.K. in its research institutes and by the manufacturing industry.

In the field of thermal generation, the British industry is also proving its mettle. The 550 MW Turbo-Generator Set now under construction, to be set up by the Central Electricity Generating Board, will be the first and largest of its kind in the world.

British engineers are prominent in undertaking construction of large hydro-electric power stations in all parts of the globe. The pumped-storage scheme now under execution in Ffestiniog in North Wales has attracted world-wide attention.

All this pace in growth has been possible only due to increased attention in the post-war period devoted to research and the ability of the industry to put new techniques into commercial practice.

To-day the British power industry is one of the leading exporting countries in this highly competitive field. Its export figures are breaking record each year.

The following contributions selected from the various engineering journals in Britain provide a broad view of the achievements of the British power industry in recent years and we hope our readers in Asia and Africa, who are intimately connected with power development in their respective countries, will find these instructive and useful.

In presenting this volume we acknowledge with thanks the unstinted cooperation we have received from the British Information Services.

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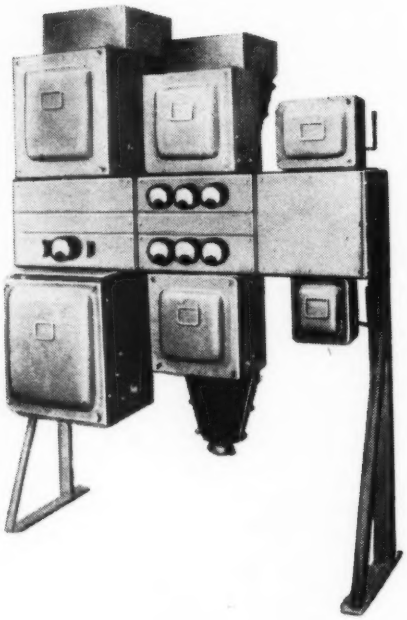

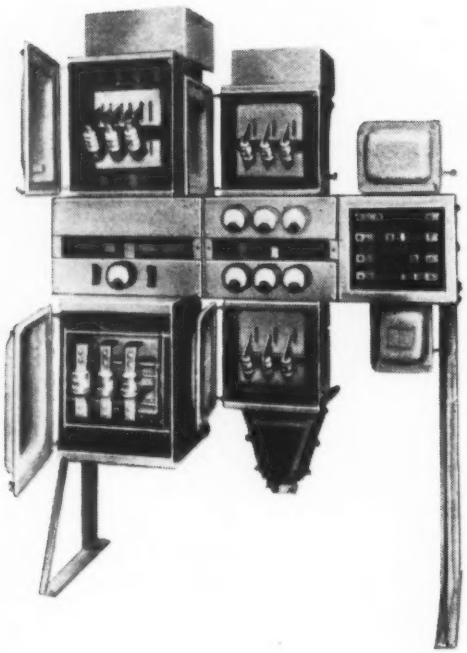

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AIC-221

Electrical Power Plant Developments in Post-War Britain

By STANLEY F. STEWARD
Director, British Electrical and Allied Manufacturing Association

Advances in the use of very high temperature and pressure conditions have produced remarkable improvements in the output and efficiency of steam plant for generating electric power. Sets which are now being constructed to operate with steam conditions of 2,300 lb per square inch pressure, 1050°F. temperature, reheating to 1050°F. are among the many outstanding developments of the British electrical power plant industry during the post-war period. At the same time the need for larger units has been met by technical developments which have resulted in sets of 100,000 kW and 200,000 kW capacities being in normal production.

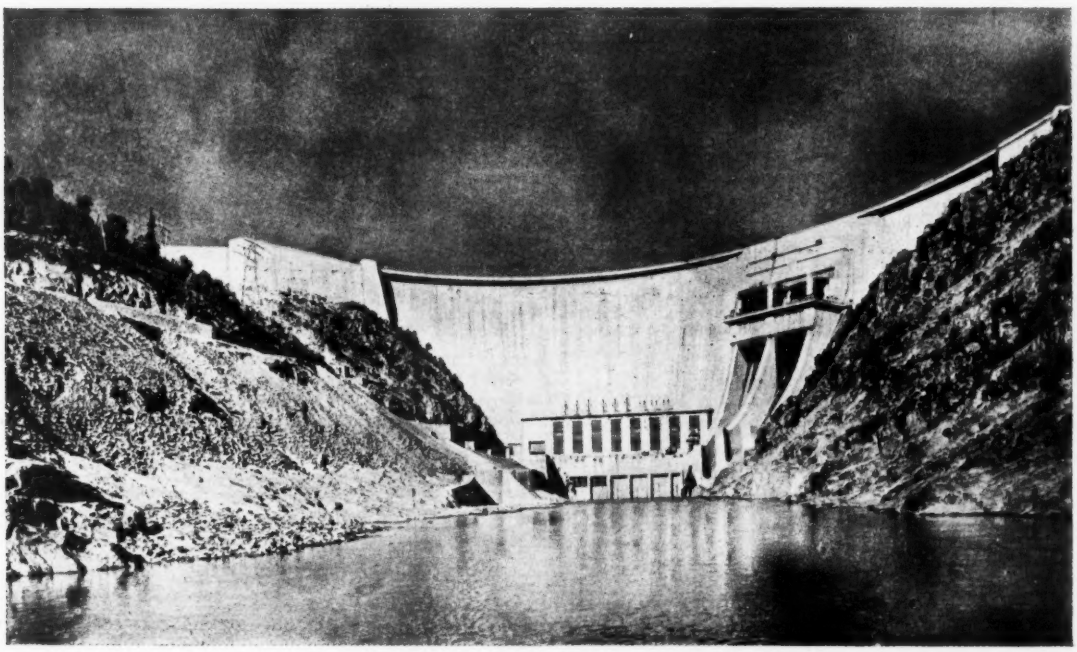
The Central Electricity Generating Board in England, recognising the economic advantages of larger units, has ordered the first 550,000 kW turbo-generator from a British manufacturer. When completed in two or three years time, this will be the largest in service in the world. It will be a cross compound unit consisting of two lines arranged in line ahead, each line comprising four turbines driving a 275,000 kW hydrogen and liquid cooled generator. Its thermal efficiency will be the highest in the country.

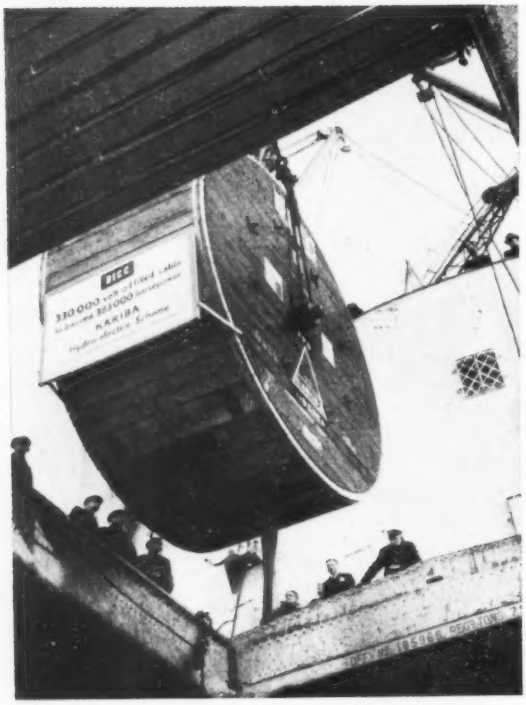
RESEARCH AND DEVELOPMENT

British manufacturers have built new factories and carried out large expansion programmes to cater for the manufacture of the largest sets and the electrical industry is, therefore, fully equipped to satisfy all demands for generating plant.

This substantial progress has been backed by considerable investment in research, in new laboratories, testing equipment and in scientific and engineering manpower. According to an official report of Scientific and Engineering Manpower in Britain, about one-quarter of the qualified engineers and scientists working in British manufacturing industries are employed in electrical engineering. Research has been especially directed to problems of nuclear power. All the major plant manufacturers play key roles in the consortiums which are building nuclear power stations for electricity supply for the United Kingdom nuclear energy programme. By 1966 nuclear stations may be supplying a quarter of Britian's total electricity output.

A view of the Castelo-do-Bode Power Station Dam in Portugal





A Drum of Cable built by B.I.C.C. being lowered into the hold of a ship enroute for the Kariba Dam Power Plant in Africa

British exports of power plant have always been a large part of the total output and British made electrical generating equipment is in service in every part of the world. In 1958 the capacity of steam turbo-alternators 1,000 kW and over exported overseas reached a new record figure of 1,130,000 kW, nearly 24 per cent. more than the capacity of plant exported in 1957.

SPECTACULAR ORDERS

Electrical manufacturers attach great importance to the winning of orders for power plant, for success helps towards the sale of other electrical equipment for transmission and distribution, and experience in the operation of British equipment promotes repeat orders when new or additional plant is required.

A good example is the Richard L. Hearn power station, Toronto, Canada, where a British manufacturer supplied four 100,000 kW hydrogen-cooled sets during 1951-3 and subsequently received orders for four 200,000 kW machines, which will bring the total installed capacity of the station up to 1,200,000 kW. This same firm later received order for two machines of 300,000 kW output for another Toronto power station.

Other British plant manufacturers have had similar success. Two British sets of 200,000 kW output will be supplied to a new station 70 miles north of Sydney, New South Wales, under a contract awarded in June this year. They will be Australia's first 200,000 kW machines and when the power station is completed it will be the largest in the southern hemisphere with a total installed capacity of 1,500,000 kW. At a new power station in Buenos Aires, Argentina, five British 120,000 kW reheat turbines with hydrogen-cooled generators will be installed under a contract concluded in 1958. Another two machines of similar size are also being manufactured for Elektrim, Poland.

These are examples of the more spectacular orders won by the British industry. Numerous smaller plants are being supplied to other parts of the world, for public supply, for steel-works, mining and industry. In this highly competitive field Britain has maintained its leading position by up-to-date designs and vigorous sales effort.

HYDRO-ELECTRIC ACHIEVEMENTS

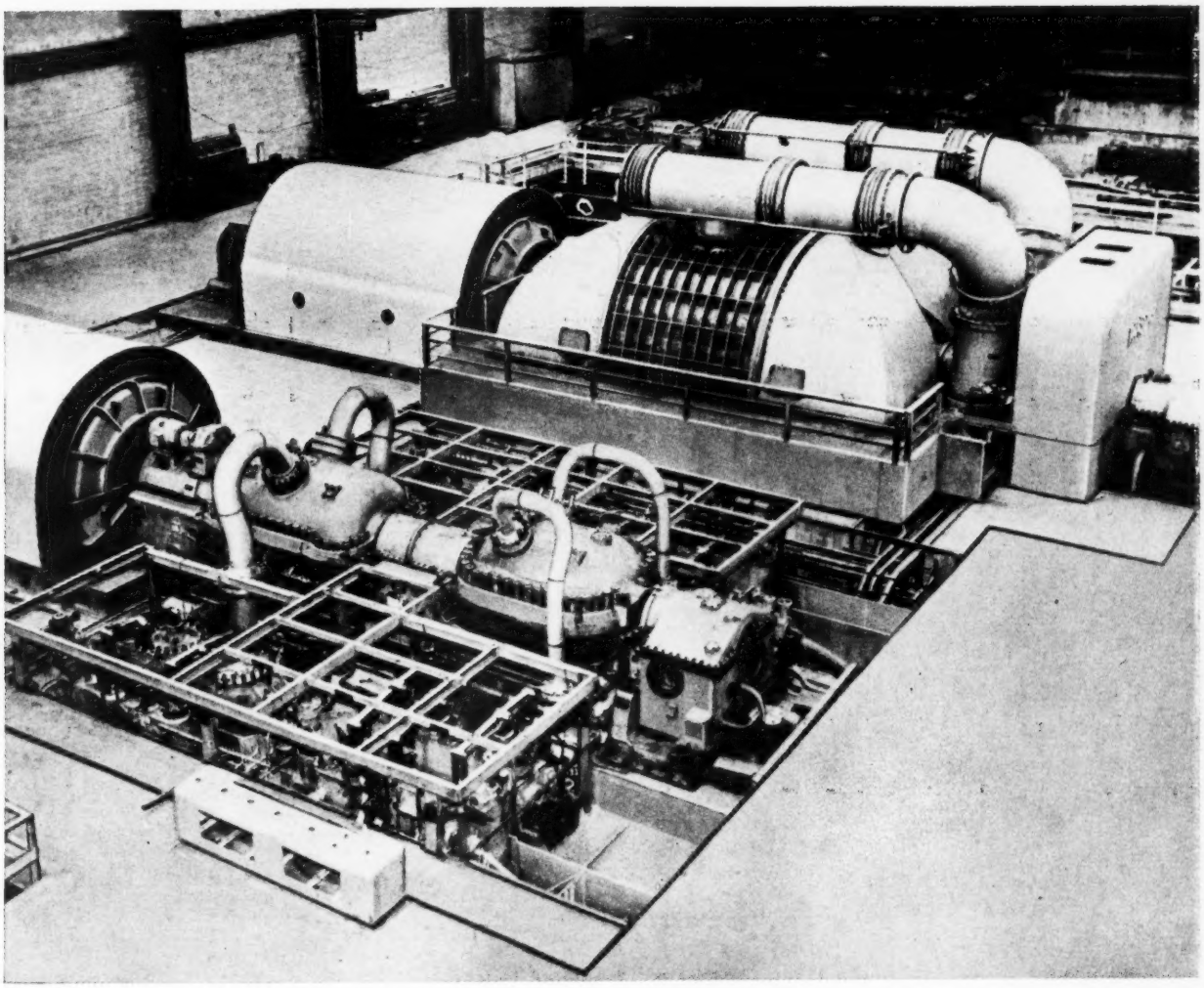
In many parts of the world, hydro-electricity is the most important source of power. About one-third of electricity generated in the world is, in fact, produced from water-power resources. Since the war the harnessing of these resources has been on a scale far greater than any preceding period, and an important share has been carried out by British engineering firms. British water-turbines have been supplied or are under construction for Australia, Brazil, Canada, India, New Zealand, Portugal, Rhodesia, Spain, Turkey, Uganda, and the United States.

One scheme which has attracted world interest is the Kariba project on the Zambesi River in Africa. Six 100,000 kW vertical waterwheel alternating current generators are now being built by a British manufacturer for the first stage of development. The project will eventually have an installed capacity of 1,200,000 kW. Other large British turbines comparable with those made anywhere else are being supplied to the United States for the Priests Rapids Power Station. These are each capable of developing 131,000 h.p.

PUMPED-STORAGE SCHEMES

A development of considerable significance in hydro-electric engineering is in the pumped-storage field. The essentials of a pumped-storage scheme are upper and lower reservoirs connected by pipe-lines and a combined pumping and generating station arranged so as to pump water from the lower to the upper reservoir when demand for electricity is low and to use the water for generating power at times of peak demand. In this way the electricity supply system may be used to best advantage and the economies of power generation greatly improved.

The largest pumped-storage scheme in the world is now under construction at Ffestiniog in North Wales where an installed capacity of 300,000 kW is planned. An upper reservoir is being formed by enlarging an existing lake, the lower will be of entirely artificial construction, the difference in levels being about 1,000 ft. The scheme will work in association with a



220 MW Turbo-Generator at Richard L. Hearn Power Station, Toronto

new nuclear power station to be constructed in the area, it being of particular importance for nuclear stations to operate at high load factor. Experience of this scheme will be of immense value to the British firms concerned in its construction, and it seems likely that similar schemes could be economically justified in other parts of the world.

Britain's electrical manufacturers emply 750,000 workers and the annual output of electrical goods is worth more than £1,300,000,000. In 1958 nearly £300,000,000 of British electrical exports was sold overseas, making an outstanding contribution to world economic development.

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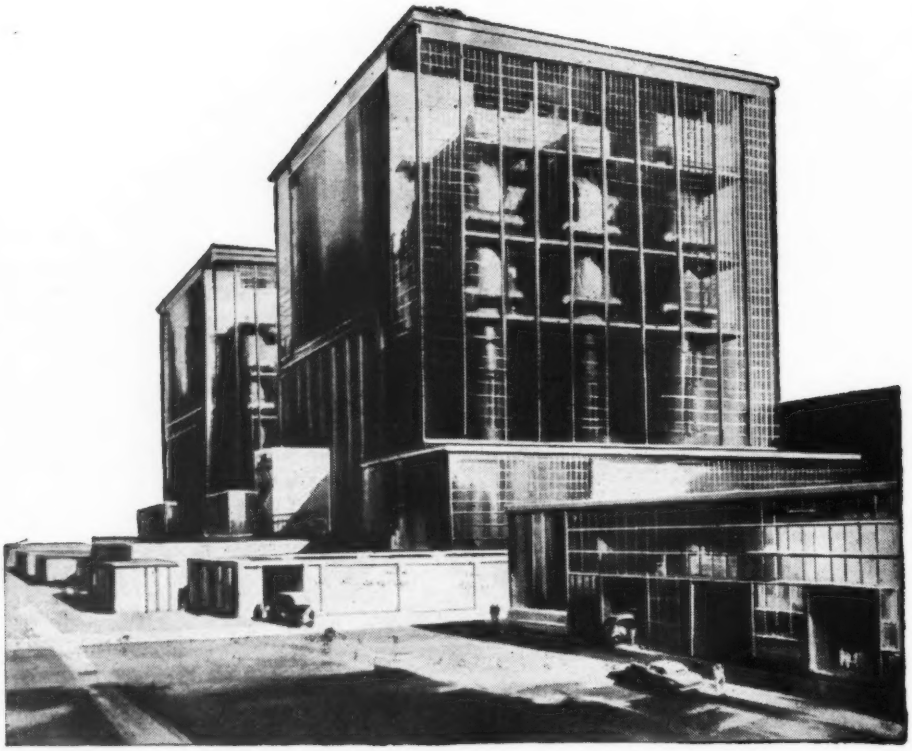

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Current Developments in Nuclear Power in Britain

By W. R. WOOTTON
Deputy Manager, Atomic Energy Department
Babcock and Wilcox Limited

It is now five years since Britain's Programme of Nuclear Power was introduced in February 1955 and it is indeed most appropriate to use this occasion to review these past five years and to look forward to the next five or ten. Those sections of British Industry that have borne the burden of these developments have all profited by the experience, for there was, and is, much to learn—of lessons that often can be learnt only the hard way. It is for such reasons that it is a pleasure to receive an invitation to share some of these experiences with people who are themselves expecting to accept similar burdens in the near future.

Many of you will recall that the 1955 Nuclear Programme in Britain envisaged the completion of 1500 or 2000 MW of nuclear power plant by 1965 which would save about 5 or 6 million tons of coal yearly; this would represent 10% of the amount expected to be used then for electricity generation. In response to this programme, Industry tendered for the first two nuclear power stations—Bradwell and Berkeley, respectively in the east and west of England—in October 1956. The most surprising thing about these tenders was the size of the reactors; they were three times as big as Calder Hall and it was at once made quite clear to the Government that Industry was prepared to meet the challenge of nuclear power plant construction with an ability and a boldness that had not been foreseen. It was for this reason that the British Nuclear Programme was amended within two years—in February 1957—and, although extended by one year to 1966 instead of 1965, now envisages 5000 to 6000 MW of nuclear power plant to be completed by then; this would save between 16 and 18 million tons of coal yearly, or about 25% of the amount expected to be used for electricity generation at that time.

In fulfilment of these ambitions, there are now five nuclear power stations under construction—Berkeley, Bradwell. Hunterston, Hinkley Point and Trawsfynydd—aggregating 1900 MW. Tenders have just been submitted for the sixth—Dungeness—and, within a few months, the seventh, Sizewell, will also have been submitted. This will bring the total to about 3000 MW and it is confidently expeted that 1000 MW of nuclear power plant will continue to be ordered each year—1961, 1962 and 1963—so that 5000 MW will definitely be completed by 1966, with the prospect of 6000 MW very soon thereafter.

It is impossible to exaggerate the importance to Industry of having a National Programme of Nuclear Power; if a country has ambitions not only to harness the atom to its power requirements but to establish an identity in the science at the same time, it is imperative. The development of nuclear power is exceedingly expensive and quite beyond the means of individual firms. In Britain, it has been the constant encouragement of the bold National Programme that has enabled the Engineering Industry there to plan its participation within its resources and to carry the heavy burden. And this itself has been accomplished only by consort between mechanical, electrical and civil engineering firms. Until recently, there were five British Nuclear Consortia and, under the programme outlined earlied, i. e. an expectation of 1000 MW per annum, each could look forward to participation in 200 MW per annum which, at current capital costs, amounts to £20 million (or 55 million dollars) yearly. Even then, however, the running cost of each of the Consortia approaches 10% of this figure despite the fact that the Consortia collaborate in most important fields of research and interchange information on the Nuclear Power Collaboration Committee.

BRITAIN'S CHOICE OF REACTOR TYPE

In the U.K., there is very little access to uranium enriched in the fissile isotope U235. There is, at Capenhurst in the North of England, a gaseous diffusion plant for the enrichment of uranium but its output is almost entirely taken for defence purposes. Plants like these are very expensive—100 million dollars or more—and can be contemplated for peaceful purposes only if the throughput of uranium is large. For example, if Britain has 5000 MW of nuclear power plant in commission by 1965, then the annual consumption of uranium at that time will be just under 2000 tonnes; this is just on the threshold of being an economic throughput for a diffusion plant designed to produce low enrichment. In the meantime, she has to make recourse to the use of natural uranium although her future plans include the use of low enrichment.

Basically there are only two reactor concepts capable of using natural uranium; there is the heavy-water moderated reactor, which is being actively pursued by the Canadians and the Scandinavians, and the graphite-moderated reactor like those at Calder Hall. The production of heavy water is costly in terms of electrical power consumption and is appropriate to countries with considerable hydroelectric resources where excess water flow can be turned to its production. Britain has relatively meagre hydroelectric resources. Again, at the time when she was formulating her ideas for a nuclear power programme, during the years 1950-1955, she could look back upon some considerable experience in the design and construction of graphite-moderated reactors; there was Gleep,

then Bepo, followed by the twc plutonium producing reactors at Windscale and there was the work of design and partial construction of Calder Hall. It is not surprising that the graphite-moderated reactor formed the basis of her aspirations. Further, there were indications that the fuel would be quite cheap; raw natural uranium cost about 30,000 dollars per tonne and, after fabrication into fuel elements, about 60,000 dollars. Since, upon grounds of long-term reactivity, a burn-up of several thousand megawatt days per tonne was confidently expected, the fuel cost promised to be less than 1 mill per thermal kilowatt. This was appreciably cheaper than coal or oil in Britain.

The decision to base the country's nuclear power programme on natural uranium has so far withstood the test of time. It is very unlikely that any alternative concept of reactor would show an advantage under the financial structure prevailing there, viz. relatively low rates of interest. Of far greater importance still is the independence enjoyed by a country whose nuclear power programme is based upon natural uranium, enabling it to make its purchases of fuel in the open world market; in comparison, dependence upon supplies of enriched uranium from a foreign country, though confidently assured in times of peace, leaves much to doubt in times of war.

THE FIRST ROUND OF NUCLEAR POWER PLANT

The 8 reactors at Calder Hall and Chapelcross were the result of a 2-year study commenced in 1951 and culminating in 1953 when orders were placed with a large number of industrial firms for their construction. The first of these reactors became critical in May 1956 and the last in December 1959. All are now in satisfactory operation with an output about 20% greater than that for which they were designed, viz. 220 MW instead of 180. Each has an investment of 130 tonnes of natural uranium which is allowed to reach a maximum temperature of about 600°C; at temperatures much higher than this, uranium undergoes a metallurgical change which is accompanied by undesirable swelling. The uranium rods are encased in sheaths of magnesium alloy and this would otherwise rupture as a result of this swelling. Magnesium alloy is chosen because of its good contribution towards neutron economy but it also had a temperature limitation, viz. 430°C, above which its strength was inadequate. The Calder Hall reactors run with a sheath temperatue of 410°C, enabling a coolant temperature of 330°C to be reachd. This in turn enables steam to be generated at a temperature of 320°C and a steam cycle efficiency of 20% to be attained.

During the several years of operational experience so far accumulated on the plant, the following facts have emerged:

(1) Teething troubles were practically non-existent, an unexpected result bearing in mind the novelty of the plant; the only significant one was the loss of coolant—about 1 ton daily of carbon dioxide—and this had no tangible economic penalty, so little was its cost.

(2) The self-controllability of the plant was unexpectedly good; over an appreciable range of load, the output can be controlled simply by regulating the flow of coolant through the reactor.

(3) Bearing in mind that the plant is not designed for on-load fuel replacement but has to be shut down and depressurized, the time taken for this operation is remarkably short, only one month. This means that the plant is capable of carrying a load factor of 92% if so required.

(4) The incidence of faulty fuel elements has been very low, no more than 4 or 5 per charge of 10,000 fuel elements.

When Industry submitted its first Tenders to the Electricity Authorities for their first nuclear power plant, it was in the same month as Calder Hall's No. 1 Reactor was officially declared open by Her Majesty the Queen—October, 1956. There was very little experience at that time upon which to draw. However, research in the laboratories upon natural uranium fuel elements indicated that, while the temperature of the uranium metal still could not exceed the 600°C upon which Calder Hall was designed, the temperature of the sheath could be raised from 430°C to 450°C, and of the coolant from 330°C to 396°C. These, in themselves, would not have had a very startling effect on the thermal efficiency attainable by the station if it were not for an increase in coolawt pressurization which was simultaniously achieved. This resulted from the ability to fabricate the reactor pressure vessel in steel 75 mm. thick as compared with 50 mm. used at Calder Hall. In turn, the pressure was raised from 7 to 10 atm. and allowed the temperature of the colant entering the reactor to be raised from the 140°C at Calder Hall to 200°C. Altogether, the advancements enabled the thermal efficiency offered in these Tenders for the Electricity Authorities to exceed 28%, compared with 20% at Calder Hall, i. e. 40% more output over which to spread the capital cost. At the same time, of course, the electrical output of the plant was increased by a factor of 4, the 2-reactor stations having an electrical output of 300 MW. Their cost was about 110 million dollars—365 dollars per kilowatt—exluding the cost of the site and of the first charge of uranium. Each reactor required 240 tonnes of uranium, i. e. 27 million dollars worth for the whole 300 MW station. Operating at a load factor of 80%, the cost of generation of electricity was expected to be under 9 mills per kilowatt-hour made up as follows:

10%annual fixed charges	5.4
Fuel consumption 103 tonnes p.a.	2.0
Fuel inventory charges	0.6
Operation and maintenance	0.7
Operation ahd maintenance	0.7
Mills per kilowatt-hour	8.7

The later stations in the first round of Tenders for the British Electricity Authorities are both 5C0 MW, each comprising 2 reactors of 250 MW net electrical output. They are characterized by a further eleva-

tion in coolant pressurization, 14 atm. in the case of Hinkley Point and 18.5 atm. for Trawsfynydd. These stations lead the way for the immediate future since it is unlikely that much bigger units will be adopted by the Authorities until further operational experience has been accumulated. Hinkley Point costs about 150 million dollars—300 dollars per kilowatt—again excluding the site and the first charge of uranium. The latter amounts to 370 tonnes for each of the two reactors, costing 41 million dollars for the whole 500 MW station. Operating at a load factor of 80% the cost of generation of electricity is expected to be under 8 mills per kilowatt-hour made up as follows:

10% annual fixed charges	4.3
Fuel consumption 188 tonnes p.a.	2.3
Fuel inventory charges	0.6
Operation and maintenance	0.6
Mills per kilowatt-hour	7.8

Considerable commercial secrecy surrounds current efforts in the design of these 500-600 MW nuclear power stations for the British Electricity Authorities but it is probable that they are expected to cost about 275 dollars per kilowatt, have an efficiency of 30% and generate electricity at a cost of 7 mills per kilowatt-hour made up as follows:

10% annual fixed charges	3.9
Fuel consumption 162 tonnes p. a.	2.0
Fuel inventory	0.5
Operation and maintenance	0.6
Mills per killowatt-hour	7.0

There is considerable controversy in Britain as to the prospects for further improvement in these reactors of the Calder Hall type, that is to say in gas-cooled, graphite-moderated reactors using metallic uranium sheathed in magnesium alloy. It is unlikely that their efficiency (at least for the largest sizes currently contemplated, viz. about 300 MWE) will exceed 35% chiefly because the foreseeable limitations in thickness and strength of the steel plate used in the construction of the reactor pressure vessel are 150 mm. and 1.5 times that of mild steel respectively. Together, these indicate a maximum coolant pressure of about 50 atm. and, while this will allow considerable elevation of the temperature of the coolant entering the reactor, the temperature limit at the reactor outlet will continue to be that dictated by the use of metallic uranium, viz. 600°C, and magnesium alloy, perhaps by then 500°C. Nevertheless, this efficiency of 35% means that there will be another one-sixth more output over which to spread the capital cost and, if this accompained by a 10% reduction in the cost itself (which is also foreseeable), then the cost of generation of electricity would fall to about 6 mills per kilowatt-hour. This still assumes a load factor of 80%, as in the previous cases.

THE FUTURE OF THE GAS-COOLED REACTOR

It is a well-known fact that, where capital costs of power plant are high (as in the case of current nuclear stations) and fuel costs are relatively low, it is imperative to load such stations with the highest possible load factor. It is for this reason that the cost of generation of electricity by nuclear power plant is invariably calculated at a load factor of 75 or 80% and then compared with conventional stations operating at the same load factor. In Britain, it would in fact be more appropriate to compare the stations upon the basis of a load factor of 55% for two reasons: The first is that this is nearer to the real annual load factor of the country and the second is that this is the weighted mean of a plant which, during the 20 years of its expected life, operates during the first five years at 80% load factor, the next at 60% and the last ten years at 40%; other new plant has, of course, come into commission in the meanwhile, the higher efficiency of which will undoubtedly encourage it to be given the greatest possible fraction of the available load.

It would seem to be only fair, therefore, to compare current nuclear and conventional stations upon this load factor of 55%. The result is that the 500 MWE nuclear station, costing 275 dollars per kilowatt and having an efficiency of 30%, would produce a kilowatt-hour for 9 mills, rather than the 7 mills referred to earlier in connection with a load factor of 80%. The conventional station, costing less than half as much and burning coal at 12 dollars per ton with an efficiency of 35%, would produce a kilowatt hour for 8 mills; nuclear power in Britain is still, therefore, 10 or 12% more costly than conventional. It was pointed out earlier that foreseeable developments in the basic Calder Hall type of reactor seem to promise to bridge this gap but an alternative is the Advanced Gas-cooled Reactor, a concept in which metallic uranium is replaced by a ceramic, uranium dioxide, and the magnesium alloy sheaths are replaced with beryllium or stainless steel capable of much higher temperature. The aim is to take the heat away from the reactor at a temperature sufficiently high to enable steam at typical modern conditions to be attained, e.g. 150 atm. 550°C, in turn enabling up-to-date technology in both boilers and turbines to be applied to nuclear power plant. It will be recalled that steam temperatures are currently limited to about 400°C in present nuclear power plant.

A prototype of the Advanced Gas-cooled Reactor is in course of construction near Calder Hall and will drive a 30 MW turbogenerator. It will be commissioned next year. It is moderated with graphite and cooled with carbon dioxide. The uranium will be slightly enriched and this has been one of the principal reasons for controversy over this line of development; obviously stations of this type will require enrichment plants to support them or else imported fuel and inveitable dependence upon the security of foreign supplies. However, the concept is such an attractive one that, if it transpires to be the success confidently expected of it, will certainly be followed by the construction of enrichment facilities to support a considerable

programme of such stations; fortunately, the degree of enrichment is so low as to ensure that an optimized diffiusion plant can be built with adequate economy.

The potentialities of the Advanced Gas-cooled Reactor are considerable; foreseeable coolant temperatures approaching 600°C will enable supercritical pressure, reheat steam cycles to be adopted having an overall station thermal efficiency of 40%.

It is of interest at this stage to discuss some of the repercussions of departing from natural uranium in a large national programme of nuclear power. In the first place, it is quite clear that the capital cost of nuclear power plant capable of burning natural, rather than enriched, uranium is high; plant of the type currently being built in Britiain has been referred to as "cumbersome" and requires tens of thousands of tons of steel in their construction. It is only because natural uranium is relatively cheap in terms of its available calorific value (which is 10,000 times that of coal) that the cost of generation is at all competitive; for instance, if nuclear and coventional stations both generate electricity at 7 mills per kilowatt-hour, the breakdown of this cost in terms of capital charges, fuel bills and operating expenses is as follows.

	Nuclear	*Conventional*
Capital charges	55%	25%
Fuel bills	35	65
Operating expenses	10	10

Obviously, the focus of attack on the cost of nuclear power must be upon the capital cost, even if the fuel bills happen to increase at the same time, as would be expected to be the case if enriched uranium instead of natural were to be used as the basis of design. The argument of "availability of capital" is an important one; if the cost of generation of electricity in both nuclear and conventional stations is the same but the former requires a capital outlay of 140 million dollars for a 500 MW station and the latter only 60 million dollars, the interest of many countries throughout the world in nuclear power naturally cools off.

This is, then, another aim of the Advanced Gas-cooled Reactor: To reduce the capital cost despite the possibility of an increase in the cost of fuel arising through enrichment. The Americans are sufficiently interested in this type of reactor as to build one at Oak Ridge. The only fundamental difference between the British and American versions is the use of helium instead of carbon dioxide as the coolant. The two countries are co-operating in this field by exchanging experiences gained in the design, construction and eventual operation of the two plants.

SMALLER REACTORS

In Britain, single reactors in the size range between 150 and 300 MWE have been fully engineered and their costs and economics are known with reasonable certainty. Smaller units, still basically of the Calder Hall type, have also been engineered in sufficient detail to enable their potentialities to be assessed. Amongst these is the 100 MWE plant, comprising a single gas-cooled, graphite-moderated reactor of 300 MWT, a pair of steam raising units and a single turboalternator. The overall thermal efficiency of the station is 33%, the bulk of the steam being generated at a pressure of 100 atm. The coolant pressure is 35 atm. Built as a single-reactor station, the cost would lie between 400 and 450 dollars per kilowatt and the cost of producing a kilowatt-hour would be between 9 and 10 mills. No plant of this size is, however, being built at the present time by Britain.

Still smaller plants of the Calder Hall type are being studied, one approach being to derate the design parameters and dispense with much of the need for advanced fabrication technology both in the workshops and in the field. The principle behind this is that those countries most likely to be interested in reactors of only 20 or 30 MWE are likely, at the same time, not to have an advanced technology in heavy engineering; yet they would naturally desire to participate in local manufacture of as much of their first plant as possible. An additional reason is that greater reliance can be placed upon the performance of fuel elements when they are operating at low ratings and this may be of importance in a country distant from the source of fuel replacement.

These derated plants, humorously referred to as "tin-can reactors" or "boites a conserve", are designed to operate with coolant pressures of only 5 atmospheres, the reactor pressure vessels being only 30 mm. thick and of simple, cylindrical shape. The fuel elements have a mean rating of only 1.2. MW per tonne compared with 2.6 at Hinkley Point. The overall thermal efficiency exceeds 20% and the overall cost lies between 500 and 600 dollars per kilowatt. The plant would be expected to produce electricity at a cost of 15 mills per kilowatt-hour without claiming any reimbursement for the plutonium content of the irradiated fuel. As a matter of general interest, the graphite core of a reactor for 20 MWE is a right cylinder 7 metres in height and diameter, not including the reflector; it has an investment of 60 tonnes of natural uranium.

An interesting possibility to connection with these small reactors is that they can be made the centre of combined research and development facilities: The reactor area can be arranged to have many thermal columns, beam ports and experimental access ways enabling much important research in radiation environments to be carried out. With a pure research reactor, in which the heat produced is invariably wasted, the cost of fuel alone is prohibitive, at least in the large sizes, but in the case of the "small" power reactor (in which the thermal output, incidentally, equals that in a large research reactor), the sale of electrical power heavily subsidizes the cost of operation of the plant as a research and development facility. Further, training for engineering personnel in the design, construction and operation of the plant leaves nothing to be desired since the plant has all the characteristics of the larger ones.

UNIT NUCLEAR STEAM GENERATORS

Amongst the reasons for the present high cost of nuclear power plant is the lack of compactness in the

layout. At the time of the Calder Hall feasibility study, there were good reasons for keeping the "boiler heating surface" well away from the "nuclear furnace"; amongst these was the question of inspection and repair of the boiler tubes. Yet at that time it was not known whether entry into the heat exchangers would, in fact, be permissible, even if they were well away from the reactor itself, and a design was developed in which repairs to faulty tubes could be effected from the outside. It is now known, of course, that entry is certainly possible and that, in any case, the incidence of boiler tube failure is apparently very remote, there having been not a single instance of leakage occurring during operation of the plant up to date. For these reasons, consideration has been given in Britain to installing the reactor and the heat exchanger surfaces in the same pressure vessel, thus dispensing with the expensive coolant ducts as well as saving space and weight. Many variations to this basic idea are possible but one attractive possibility is that of locating the heat exchanger above the reactor in a vertically elongated pressure vessel. There would be a thermal shield inside the vessel between the reactor core and the heat exchanger, this being so arranged as to permit the hot gases from the core to rise upwards into the tubular surfaces but at the same time to stop radiation. After their passage through the tubular heating surfaces, the cooled gases would flow downwards close to the walls of the pressure vessel, keeping them cool, until they reached the circulating blowers. These would be arranged as excrescences near the base of the vessel. The whole unit would resemble much more closely the orthodox pattern of power plant boiler and appreciable economies are expected in cost of manufacture.

FUTURE DEVELOPMENTS IN BRITAIN

When the construction of Calder Hall was embarked upon, it was realized that steps would have to be taken to improve the burn-up of uranium in the long run. Certainly, in each kilogram of uranium there are only 7 grams of fissile material and reactors of the Calder Hall type could burn about 3 of these but of greater importance is the indication that all the uranium is potentially capable of being burnt. This is apparent from the fact that, for every atom of uranium fissioned, two and a half neutrons are produced of which only one is required to maintain the chain reaction; this leaves one and a half available for capture by the non-fissile uranium and the possibility, therefore, that one and a half atoms of fissile plutonium could be formed. In practice, there are several other competitors for absorption of neutrons in a reactor and, in ones like Calder Hall for example, only about 8 atoms of fissile plutonium are made for every 10 atoms of fissile uranium consumed. However, by eliminating these competitive elements, the ratio can be improved and can, in fact, exceed unity by a substantial margin. One type of reactor in which this "breeding" of fuel might be achieved is the experimental fast reactor at Dounreay in the North of Britain. Here, the core is in two major zones: The inner is highly enriched in the fissile isotope of uranium or plutonium, and the outer is a "blanket" zone of natural, or even depleted, uranium. The inner core is practically unmoderated and the chain reaction proceeds virtually on fast neutrons alone. Neutrons escaping from the boundary of the inner zone enter the blanket zone where they are captured largely by the non-fissile uranium which in turn is converted into fissile plutonium. From time to time, the blanket is treated chemically for removal of this plutonium, a little of which is "lost" in the process, and the recovered plutonium is fed into the core. Once this equilibrium is reached, the feed to this reactor can be the non-fissile uranium isotope and this obviously includes the depleted uranium rejected by the Calder Hall type of reactor after it has given up its 300 MWD per tonne there.

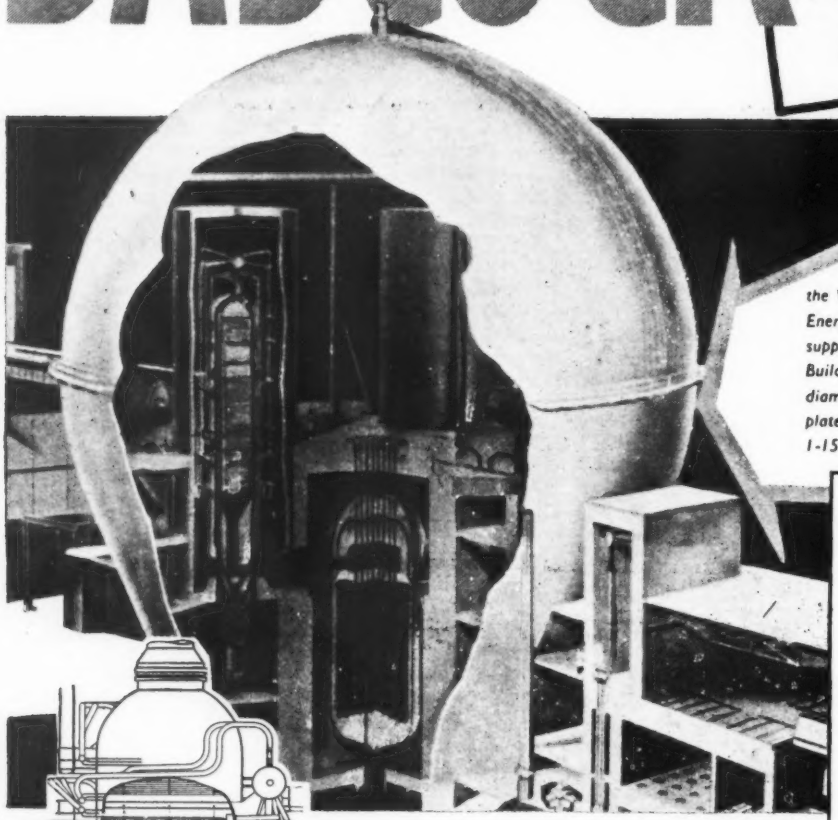
The ability to burn all the uranium instead of just the small amount of the fissile isotope means that the calorific value of natural uranium is not just 10,000 times that of coal (as stated earlier) but a million times. The entire electrical demand of the United Kingdom could be met by the consumption of less than 50 tons of natural uranium per annum. At current prices, this would cost only about 1.5. million dollars in foreign currency, a quite negligible sum. Britain's dependence for supplies of uranium from abroad—although much of its comes from the Commonwealth—makes her particularly interested in reducing the amount for reasons of security in times of international conflict. More and more emphasis is likely to be placed in Britian upon the development of reactors in which substantial amounts of the non-fissile isoltope are burnt, even if they do not achieve the fully breeding cycle. The Dounreay reactor achieved criticality a few months ago but it is too early to ascertain its performance. Once again there is a very close association and interchange of information and experience between the British and Americans who themselves are building a major power plant based on the fast breeder reactor—the Enrico Fermi station near Detroit.

It will be evident from the foregoing that almost all the development in nuclear power in Britain up to the present time have been inspired by what called the "nationalized effort". More recently, however, there have been departures from this pattern: Certain British firms have made arrangements with American ones, enabling alternative concepts of power reactor to be manufactured in the United Kindgom and sold there or abroad; other British firms have developed their own, unique concept of reactor. This has been particularly the case in the field of nuclear marine propulsion upon which emphasis has been placed in Britian during the past 2 years. Somewhat less than a year ago, submissions were made to the Government by eight different concerns in a competitive atmosphere. One of these was the nationalized Atomic Energy Authority and this body was alone in offering the "nationalized approach"; they submitted an adaptation of the Advanced Gas-cooled Reactor. Of the remainder, three submitted water-cooled reactors based upon American technology, two others submitted gas-cooled reactors quite different, however, from the "nationalized approach", one submitted an organic liquid cooled reactor and the last, a steam-cooled, heavy-water moderated design.

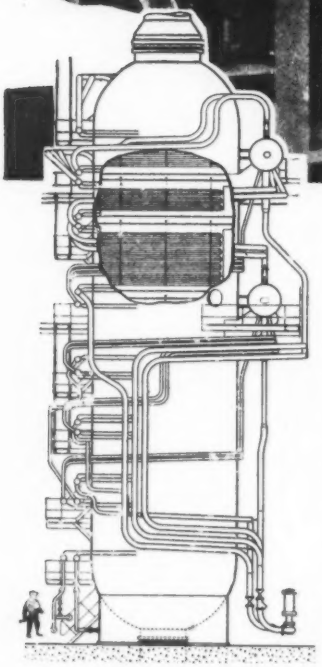
[*Continued on page 24*

BABCOCK

EQUIPMENT FOR NUCLEAR POWER



For the ADVANCED GAS-COOLED REACTOR or A.G.R., at the Windscale works of the U.K. Atomic Energy Authority, Babcock & Wilcox are supplying the domed Containment Building, 148 ft. high by 135 ft. max. diam., of welded steel construction, with plate thicknesess from ¼ in. up to 1-15/16 in.



With over 10 years experience in the nuclear field, BABCOCK & WILCOX have developed outstanding design and manufacturing facilities for the construction of nuclear power plant.

This wide basis of experience is now broadened by important arrangements for technical collaboration with The Babcock & Wilcox Company, of America, which is responsible for many major nuclear developments, both land and marine, in the United States.

This unrivalled combination of knowledge and experience enables Babcock & Wilcox Ltd. to undertake the design and construction of a range of nuclear power plant and components, for reactor systems of either the *gas-cooled* or *water-cooled* types.

Part-sectional view of one of the twelve Babcock 450,000 lb./hr. dual-pressure steam-raising units, 90 ft. high by 21 ft. 0 in. diam., for the 500 MW Hinkley Point nuclear power station.

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PIPEWORK.
PIPELINE VALVES.
EQUIPMENT FOR NUCLEAR RESEARCH.

COMPLETE NUCLEAR POWER STATIONS

For the design and building of complete nuclear power stations of the gas-cooled, graphite-moderated type, Babcock & Wilcox Ltd. are in association with the English Electric Company Ltd., bringing to such undertakings an outstanding combination of facilities and experience in mechanical, electrical and civil engineering.

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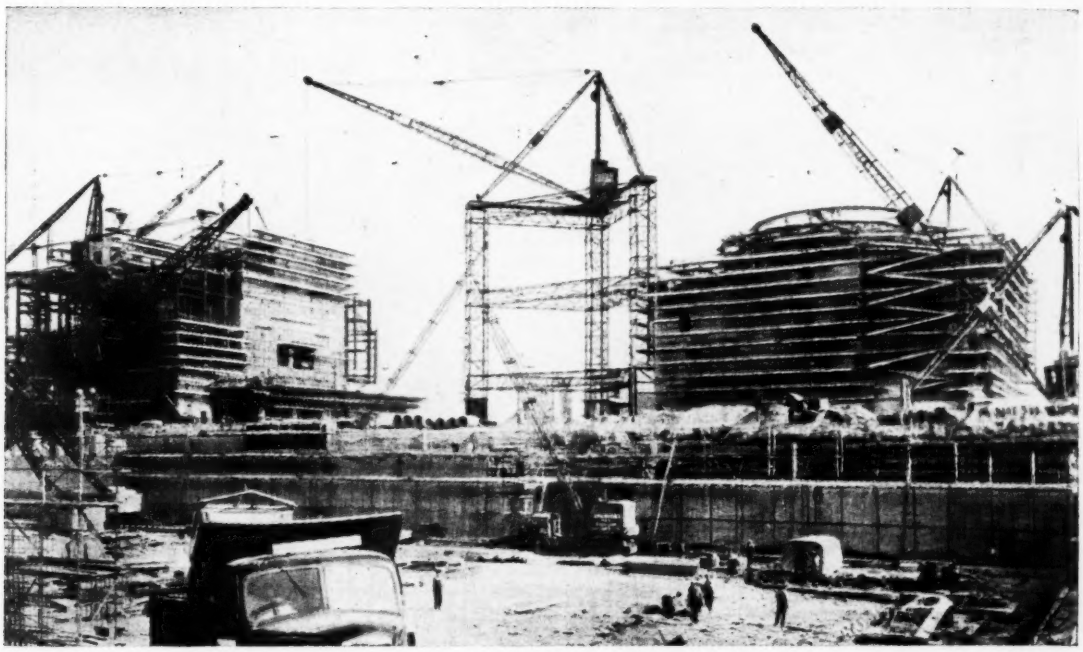
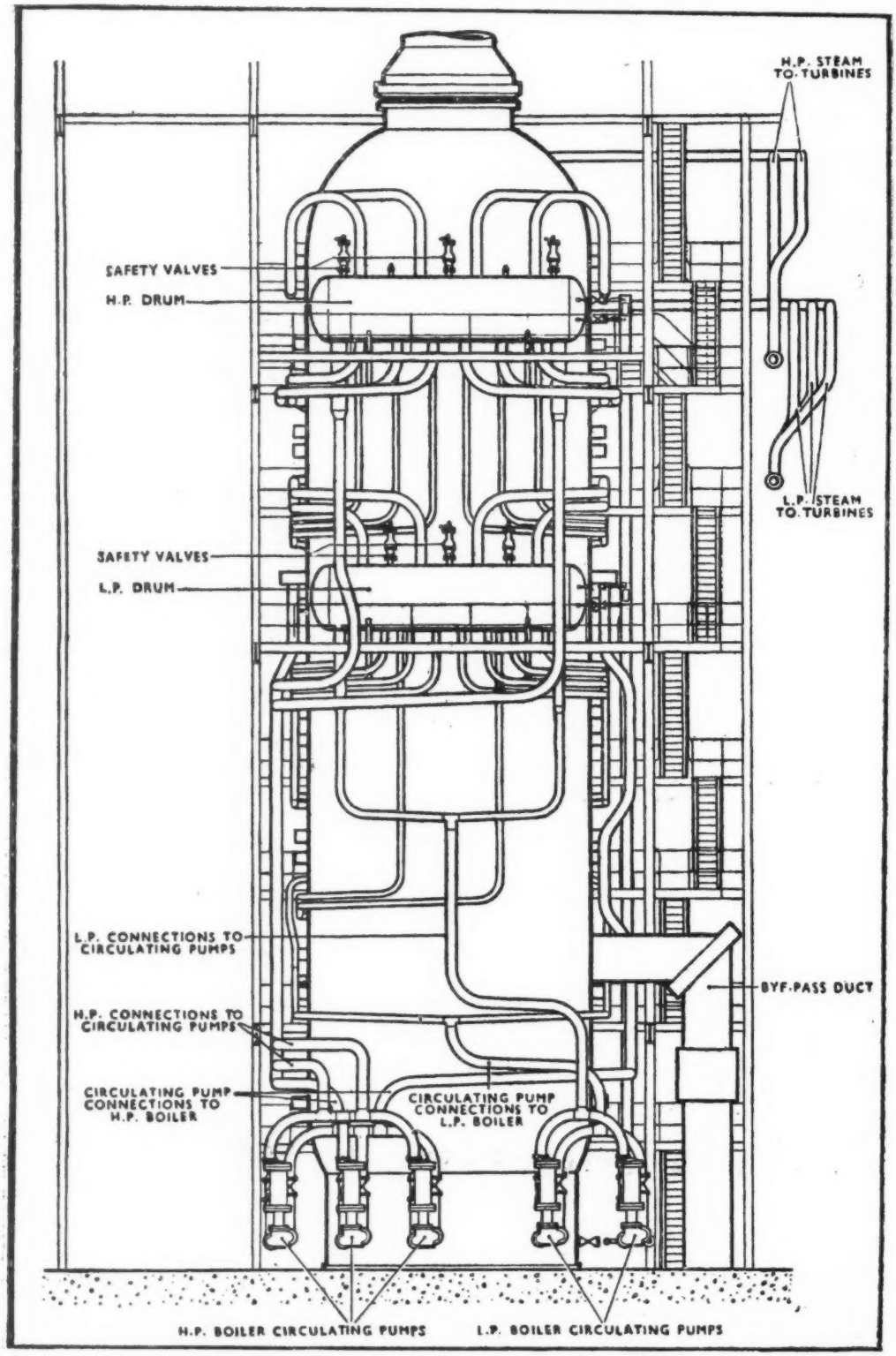
World's Largest Nuclear Power Station

The world's largest nuclear power station is being built at Hinkley Point, on the coast of Somerset, by one of Britain's nuclear construction groups—The English Electric, Babcok & Wilcox, Taylor Woodrow consortium. The station has been designed for a net electrical output of 500 MW, power being generated at 13.8 kV and stepped up to 275 kV to feed into the national supergrid. The design of the station is very compact so that its ground plan is no larger than that of a conventional 300-MW plant. For ease of running the entire station is operated from a central control room. Hinkley Point will have two reactors, fuelled by natural uranium, of the gas-cooled graphite-moderated type. Each reactor, producing nearly 1,000 MW of heat, will be connected to six axial-flow gas circulators and six steam-raising units, which will in turn feed steam to six main 3,000-r.p.m. hydrogen-ccoled turbo-alternators. Each alternator will have a C. M. R. of 93.5 MW at a generated voltage of 13.8 kV and 0.85 p. f. Three 33-MW variablespeed alternators, one of which is a standby, will supply power for the gas circulators and have enough capacity to allow for a possible increased output from the reactors.

The pressure-vessel housing the active graphite core in each of the two reactors has been designed by Babcock & Wilcox, who will also be responsible for its manufacture and erection. The vessel is a sphere of 67 ft. (20.42 m) dia to be fabricated on site from 3-in (76.2 mm) mild steel boilerplate. It will be supported by an external cylindrical skirt having a diameter of 30 ft (9.14 m.) A similar internal skirt will carry the weight of the reactor core through a structure of special design. Based on the extensive experience of Babcock & Wilcox in the field of heavy pressure-vessel construction, special techniques have been developed for the manufacture of the reactor vessel and to facilitate its accurate and speedy erection. The design and construction comply with the rules of British Standard Specification 1500 (Severe-duty Vessels) and incorporate certain additional features which will ensure a high degree of safety. The vessel has 12 openings of 6 ft 6 in (1,980 mm) dia which receive the main inlet and outlet gas-coolant ducts. In addition, there are about 170 nozzles, varying in diameter from 3 in (76·2 mm) to 2 ft (610 mm), for the charging and discharging of fuel elements, gas sampling, control-rod insertion, Wigner probes and debris removal. The total weight of the vessel, including nozzles, attachments, lagging and other fittings

Hinkley Point Power Statoin : In the background can be seen the biological shields of the two reactor buildings, in the foreground the foundations of the 750 feet long turbine hall.




H.P. STEAM TO TURBINES
SAFETY VALVES
H.P. DRUM
L.P. STEAM TO TURBINES
SAFETY VALVES
L.P. DRUM
L.P. CONNECTIONS TO CIRCULATING PUMPS
BYE-PASS DUCT
H.P. CONNECTIONS TO CIRCULATING PUMPS
CIRCULATING PUMP CONNECTIONS TO H.P. BOILER
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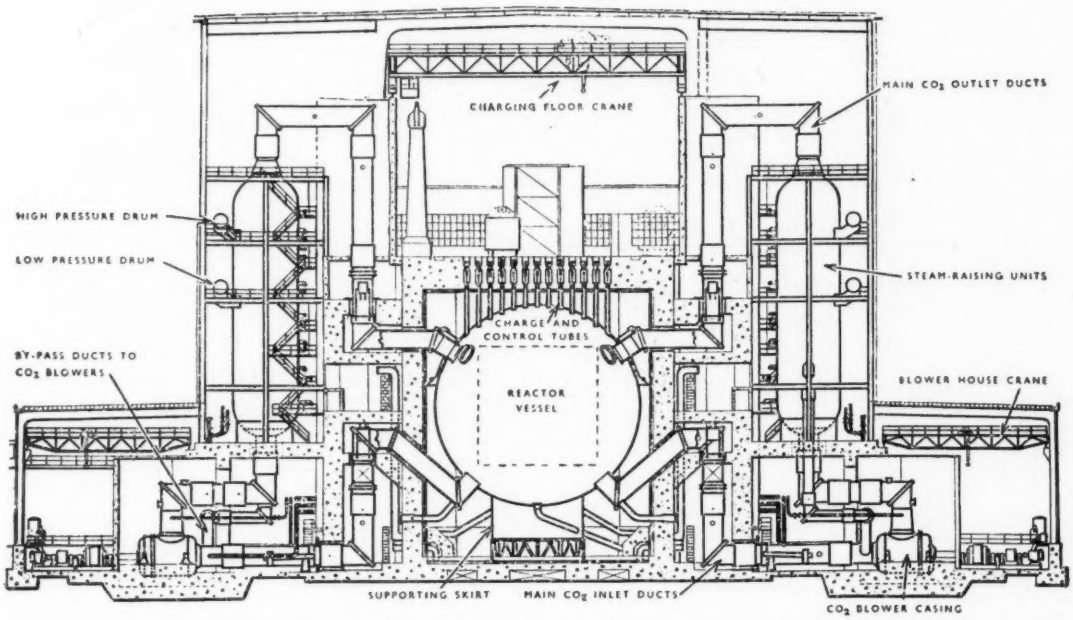


Fig. 2 Sectional view of one reactor building for Hinkley Point. There are two reactors, each with six heat exchangers, and thermal efficiency is 26 per cent. Some efficiency is sacrificed to increased output and economy.

will be approx 1,700 tons (1, 727 tonnes) and the toal load carried by the external skirt of the completed vessel its internal core and supports will be in the neigbourhood of 5,500 tons (5,590 tonnes).

The design of the reactor support is simple and robust, involving no mechanical joints, sliding parts or rolling surfaces. A simple but ingenious thermal device ensures that local discontinuity stresses in the reactor support region are kept within safe limits under all envisaged conditions of operation. The 3-in (76.2-mm) plates for site-fabrication of the pressure-vessel shell and the cylindrical plates for the support skirts will be preformed at the company's Renfrew Works, using hydraulic presses of 2,000 and 8,000 tons (2,032 and 8,128 tonnes) capacity. All shell plates, forgings and pressure attachments will undergo vigorous inspection prior to manufacture, and all construction welds will be subject to radiographic examination. The vessel will be stress-relieved *in situ* after erection, and will then be pneumatically tested to one and a half times the design pressure. The magnitude of the work involved in constructing this massive vessel is indicated by the fact that over 13 tons (13.210 kg) of weld-metal will be deposited in welding the sphere plates, exclusive of nozzle and duct openings, in the course of its fabrication.

The 24-sided core of each reactor is made of graphite blocks which contain the fuel elements and form a reflector envelope surrounding the core. This structure, which is held in position by bands round the periphery, is contained in the pressure vessel just described and is supported on ball bearings to reduce friction caused by differences in thermal expansion between the support plates and the graphite. Fuel is loaded from the top through charge pans which protect the top face and give a positive location for the charging machinery.

Each fuel element consists of a cylindrical rod of or uranium sealed in a can of magnesium alloy to prevent chemical reaction between the uranium and the coolant gas and also to contain fission products formed during irradiation. The cans, which have a finned surface to increase the transfer of heat to the coolant gas, stand vertically in the channels in the graphite core and are individually supported. As the main source of heat in the reactor is at a relatively high temperature, considerable importance is attached to having fuel of a suitable metallurgical condition and mechanical strength to retain its dimensional stability under irradiation and cans which are sufficiently resistant to both corrosion and evaporation in the coolant gas. If a fuel can fails fission products escape into the coolant gas and cause an increase in radioactivity. To avoid this, the radioactivity of the gas is measured regularly to detect any failure. This is done by taking smples of gas from each channel through standpipes to selector valves outside the biological shield. Each group of channels is sampled in this way for a period of 25 sec. every 30 min. Provision is also made for the independent monitoring of suspect channes, and the outlet ducts from the reactor are monitored at frequent intervals.

The charge and discharge equipment is designed to allow refuelling while the reactor is pressurized and on full power. Its principal components are a hole preparation machine and fuelling machine for storing new and irradiated fuel, preparing the reactor for fuelling, inserting new fuel, changing the position of

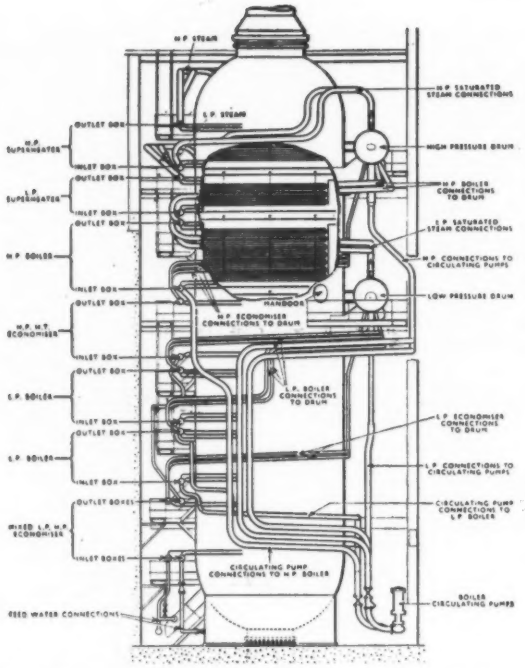


Fig. 3 The steam-raising or heat-exchanger units for Hinkley Point are based on the double-pressure cycle. The arrangement of reactors and heat exchangers is such that thermo-syphonic circulation of the coolant gas is sufficient to prevent an excessive rise of reactor temperature if forced circulation ceases.

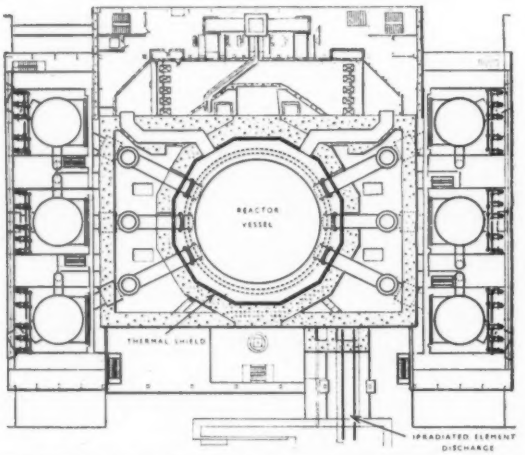


Fig. 4 Sectional plan of reactor and shielding. Charging and discharging of fuel elements can be carried out at full power with the reactor pressurised.

elements, withdrawing irradiated fuel from the reactor and disposing of irradiated fuel from machine to the storage pond. Both machines are handled by an overhead crane on top of the reactor.

The reactor pressure-vessel is contained wholly within a reinforced-concrete biological shield to protect presonnel from the radiation of the reactor. This is itself lined with a thermal shield of reinforced concrete and steel plates. The two shields are separated

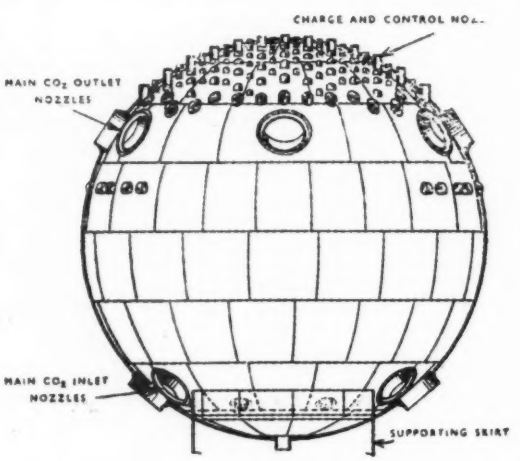
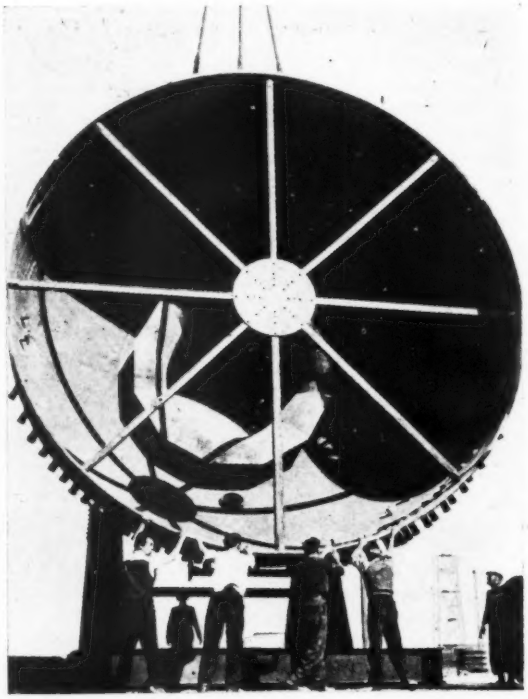


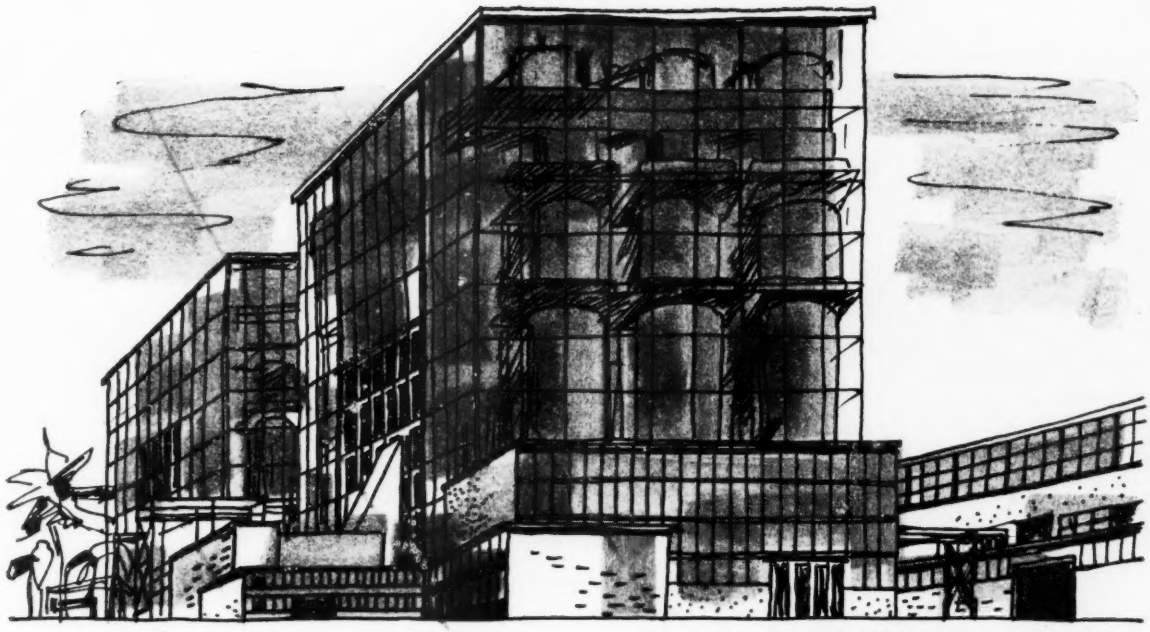
Fig. 5 The spherical pressure vessel for the Hinkley Point reactor is 67 ft. in diameter and fabricated from mild-steel plate 3 in. thick.

by cooling air passages of varying widths so that the thermal shield, with the associated cooling system, protects the biological shield from excessive temperatures arising from nuclear and thermal radiation.

Gas is circulated through the reactor and steam-raising unit circuits by axial-flow circulators. The

A domed-end is positioned for welding to a series of prefabricated ring sections to form a steam-raising unit to drive the turbo-alternators.

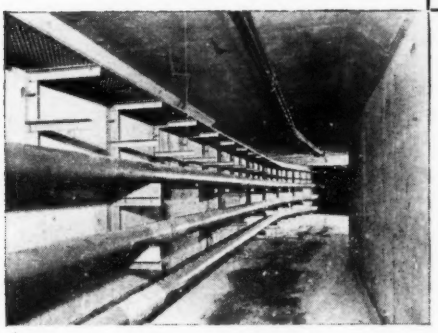




The world's first 500 MW nuclear power station under construction by The English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Group.

Biggest 275 kV cable installation in the UK by Enfield-Standard for C.E.G.B. at Hinkley Point

Enfield-Standard is currently engaged upon the manufacture and installation of 275 kV Pipe Line Compression Cables for the Central Electricity Generating Board at Hinkley Point Nuclear Power Station—six circuits at 110 MVA between the generator transformers and the 275 kV switching station.



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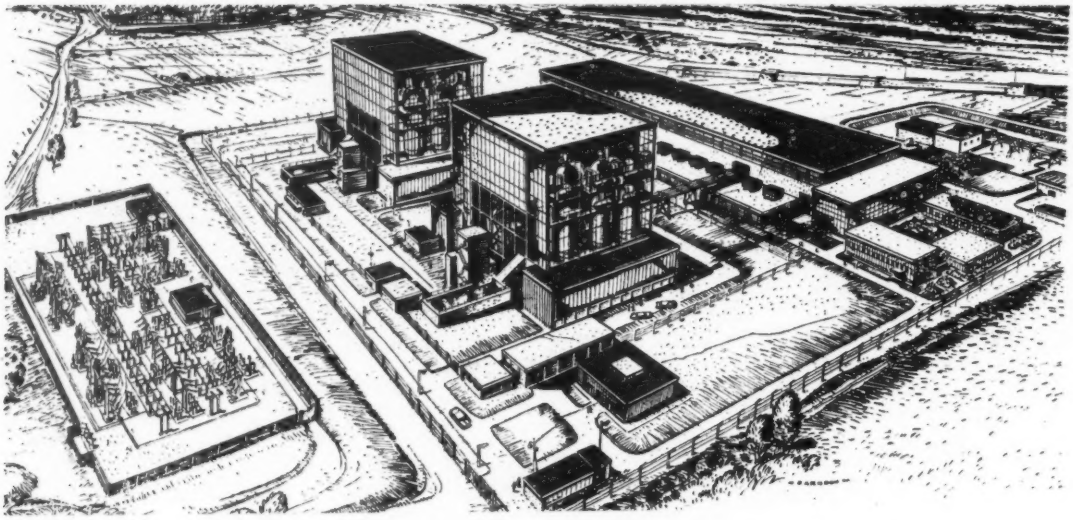


Artist's impression of Hinkley point Atomic Power Station

single-stage rotor blading is mounted on an overhung disc so that only one shaft seal is needed. The circular casing, which is of the fabricated pressure-vessel type, requires only one seal-welded flange seal against pressure in the circulator assembly. The smallest possible change in temperature of the various parts of the plant in spite of changes in the heat output is achieved by varying the gas flow through the reactor in proportion to the heat output and this variation is obtained by controlling the speed of the circulator.

The layout of the ducting system has been developed as a result of careful study of the requirements of plant simplicity, the economics of coolant-pressure drop, system flexibility and radiation shielding. The main inlet and outlet ducts carrying the coolant gas between the reactor and steamraising units will be of 6 ft 6 in (1,980 mm) dia. The flexibility required in the system to absorb thermal expansion is provided by angular-movement expansion joints fitted in each duct-run between the two plant components. Shut-off valves will be provided in the system to facilitate the individual isolation of any one of the six gas circuits, containing steam-raising units, coolant circulators and expansion joints, which are associated with each reactor.

There are six Babcock steam-raising units, or heat-exchangers, associated with each of the two reactrs, generating in total over 5.5m lb (2,5m kg) of steam/hr, divided approximately as two-thirds high-pressure and one-third lower-pressure steam. Like the steam-raising units associated with the other installations for the U. K. nuclear programme, these developments of the dual-pressure design originated by Babcock & Wilcox for the Calder Hall installation. In the case of the Hinkley Point plant, developments in the properties of the heating surface and in methods of construction and operation are such that each unit has a capacity three-and-a-half times that of a Calder Hall steamraising unit, although the height and diameter are only 20 and 25 per cent greater respectively. The main vertical shells of the Hinkley Point steam-raising units are 90 ft (27.4m) high and 21 ft 6 in (6,550 mm) dia, with a maximum wall thickness of $2\frac{3}{8}$ in (60.3mm) and they are mounted on skirt supports resting on a concrete base. The whole of the steam-raising plant is housed in buildings next to the reactor and is fitted with a ladder and gallery system to give full working access to all headers, drums and mountings. Each shell contains seven banks of heating surface made up of individually-supported, flexible, multiloop, studded elements connected to horizontal external headers through thermal-sleeve openings in the shell wall. Each bank of heating surface is surrounded by baffle plating to direct the gas flow. The extended heating surface consists of a multitude of flat studs welded to the tubes, and is a development of the Babcock & Wilcox surface formerly used in marine boiler economizers and at Calder Hall. The heat-transfer and pressure-loss characteristics of this improved surface have been determined on the test rig used for the development of the Calder Hall steam-raising units, the testing and design methods now having been proved.

The boiler banks are of a forced-circulation design, using centrifugal circulating pumps of the glandless type. Adequate standby pump capacity is provided. The steam-and-water mixture from the boiler banks passes to the respective steam separator drums which contain rows of Babcock & Wilcox steam cyclones and scrubbers to ensure that high-purity steam is led to the superheaters and turbines and also that steam-free water is handled by the circulating pumps. Incoming feedwater from the economizers also passes through the steam drum separating equipment, as some evaporation takes place in the economizer sections. Feedwater control is by 2-element automatic regulators, but emergency control of the feedwater can be

A giant crane, the largest in the world, has hoisted its own bridge 235 feet above the ground on the site. The bridge is 250 feet long and weighs 650 tons.

carried out from the station control room. The auxiliary equipment and mountings are arranged so that all normal operations, such as chemical dosing, water sampling and blow-down, can be carried out from the bottom of the units. The method of manufacture and construction of the Hinkley Point units is very similar to that used so successfully for Calder Hall. Ring-sections of the shell are fabricated with all connections at the Renfrew works of Babcock & Wilcox, completely stress-relieved at the works and transported to site. The sections are then welded together in a fabricating shop on the site and the circumferential welds stressrelieved by induction heating. After radiography and pressure testing, the completed shell is cleaned internally to a bright finish, then transported and lifted in to position by the 400-ton (406-tonne) Goliath crane. Exceptional cleanliness is maintained inside the shell throughout the installation of the banks of heating surface and other internal fittings. Warm dry air is circulated through them continuously during the erection operations and all parts entering the shells are shot-blasted to a bright surface before passing through the temporary "clean-condition houses" built round the main access openings into the shells. The multiloop elements are manufactured to stringent requirements for leak tightness and the site butt welds connecting the elements to the headers are carried out externally to the pressure shell to ensure that only those welds undergoing the works tests are inside the gas circuit. Each element projects through and is welded to the thermal-sleeve nozzle on the shell and this weld is tested under gas pressure using sensitive detector equipment. The completed units are boiled out or chemically cleaned on the water side before being put into service, using auxiliary steam injection into both high-and low-pressure drums.

The main turbines, by the English Electric Co. are of the horizontal impulse reaction design with an h.p. cylinder and two l.p. cylinders, each double-flow, solidly coupled in line. They operate on the mixed-pressure cycle, each l.p. cylinder exhausting to its own condenser, and are equipped with a feed-heating system consisting of drain cooler and feed-heater. The hydrogen-cooled alternators work at a rated pressure of 15 lb/in² (1.05 kg/cm²) gauge of hydrogen but are designed for a maximum operating pressure of 30 lb/in² (2.1 kg/cm²) guage. They have ring-type shaft seals and alternative supplies of oil to ensure safe shutdown of the sets in the event of a failure of supply. The exciter set is gear-driven from the alternator set. The turbines of the variable frequency sets are of the horizontal 2-cylinder impulse reaction type, operating at variable speed. The turbine and generator rotors are solidly coupled.

The feed-heating and condensate system is common to the whole station and that for the variable frequency sets is combined with the feed-heating system of the main sets. There are eight electro-feed pumps, six in operation under normal conditions and two acting as standby. For emergency use there are two D. C. powered standby boiler feed pumps.

The building and civil engineering work at Hinkley Point are in the hands of Taylor Woodrow Construction, Ltd. Designed as a straightforward architectural expression of their function, the buildings will have walls in flat planes relying for their effect on the general geometric pattern, and on the colouring and differing degrees of light reflection of the various forms of cladding. The steam-raising units will be clad with clear glass so that their dynamic appearance will be preserved within the neutral tones of the remainder of the reactor building. The aluminium sheet cladding of the turbine house will form a foil to the glazing used in the reactor buildings and further contrast will be obtained by coloured enamelled sheeting or plyglass in the administration buildings. The consulting architect is Frederick Gibbberd, C.B.E., F.R.I.B.A., M.T.P.I.

SUMMARY OF DESIGN

(Many of these figures are approximate only)

Net electrical output of station (2 reactors)	500 MW
Heat output per reactor	980 MW

REACTOR

Diameter of pressure vessel	67 ft
Thickness	3 in.
Weight of vessel	1,700 Tons
Design working pressure	200 p.s.i.
Operating pressure	180 p.s.i.
Gas flow	10,000 lb/sec
Outlet gas temperature	375°C
Core diameter (effective)	49 ft
Core height	25 ft
Number of fuel Channels	4,500
Lattice pitch	$7\frac{3}{4}$ in.
Channel diameter	$3\frac{3}{4}$ in.
Fuel rod diameter	$1\frac{1}{8}$ in.
Length of fuel element	3 ft
No. of elements per channel	8
Total weight of uranium	370 tons
Total weight of graphite	2,000 tons

HEAT EXCHANGERS

No. per reactor	6
Height	90 ft
Diameter	21 ft 6 in.
Thickness	$2\frac{3}{8}$ in. max.
H. P. steam	650 p.s.i. 685°F
L. P. steam	180 p.s.i. 670°F
Feed temperature	160°F
Approx. evaporation	450,000 lb/h

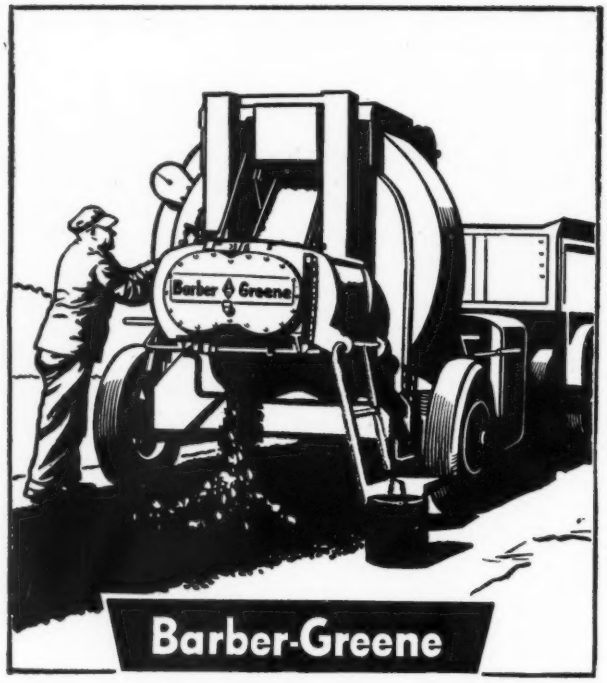
TURBINES

No. of main sets	6
Output per set	93.5 MW
No. of auxiliary sets	3
Output per set	33 MW

CIVIL ENGINEERING

Height of reactor building	175 ft
Height of biological shield	90 ft
Internal diameter	75 ft
Thickness	7 ft
Thickness of pile cap	11 ft
Secondary shield Length	140 ft
Width	100 ft
Thickness	6 ft 6 in
Weight on reactor foundation	5,500 tons
Turbine house Length	704 ft
Width	132 ft
Control room Length	70 ft
Width	60 ft
Length of Cooling water intake structure	2,200 ft
Sea wall, length	3,000 ft
Excavation required	750,000 cu yd
Concrete required	300,000 cu yd
Steel reinforcement	12,000 tons
Road construction	6 miles

[*Courtesy: British Engineering International*]



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No. 101-B. M.

Magnetic Amplifier Voltage Regulation

A major recent development is a magnetic amplifier voltage regulator of the continuously acting type. It is capable of controlling the largest alternators and will require little or no maintenance since it is static. Equipment of this type has been installed by the G. E. C. at Poole generating station in conjunction with one of their 60 MW direct cooled turbo-alternators. This article describes the equipment and also the extensive operational stability tests carried out.

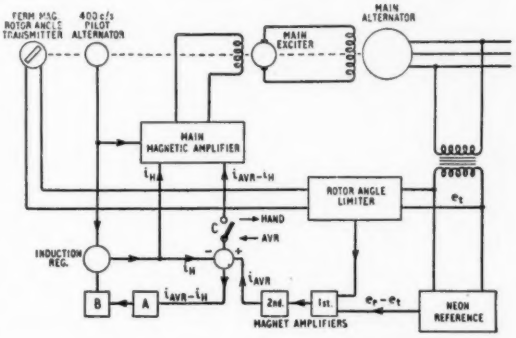
The construction and commission of the 275 kV supergrid and the continued increase in the size of individual generating units which will be directly connected to it has focused attention on the problems which may arise in day-to-day running, one of these being the stability of operation on leading power factor loads. Up to a few years ago this condition would have required alternators to be designed with a relatively higher short-circuit ratio (s.c.r.) and therefore with an inherently greater capacity to supply leading MVAr with a reasonable margin on the steady-state stability limit corresponding to a rotor load angle of 90 deg.

The development of the quick response automatic voltage regulator (a.v.r.) with no dead band has provided another solution to the problem since in permits satisfactory operation at rotor load angles over 90 deg, i.e. in the dynamic stability region. It is then possible to reduce the s. c. r. and to use the margin in rotor excitation so obtained to increase the capacity to supply lagging MVAr, i.e. to reduce the rated power factor to a value more suited to system conditions.

It is essential that the performance and reliability of the a.v.r. equipment should be of the highest order with maintenance reduced to the minimum. The General Electric Co., Ltd., has had many years' experience of the application of large magnetic amplifiers in the automatic control of industrial equipment such as colliery winders and rolling mills and also in the design of high sensitivity, quick response voltage regulators for special alternators. A major recent development is a magnetic amplifier voltage regulator of the continuosly acting type capable of controlling the largest alternators and requiring little or nc maintenance since the regulating equipment is static. From the schematic diagram (Fig. 1) it will be noted that the usual d.c. pilot exciter is replaced by a 400 c/s homopolar alternator. This high frequency supply feeds the magnetic amplifiers and gives a high speed of response for the static equipment.

Three magnetic amplifiers connected in cascade feed directly the main exciter field with a current proportional to the error between the terminal voltage and the set reference voltage. An important feature of the regulator is the inclusion of an automatic over-riding control, responsive directly to the rotor load angle, which under any loading condition will prevent the excitation from being adjusted to such a value that the preset maximum rotor angle can be exceeded.

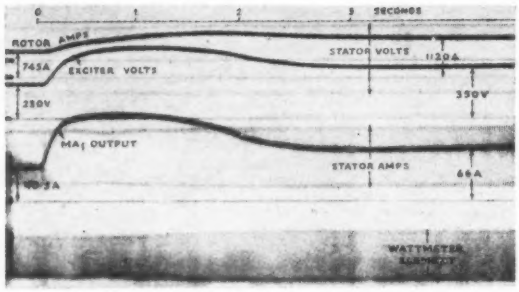
Fig. 1.—Basic diagram of automatic voltage regulator type C V.R.7 with rotor angle limiter type K.A.L.



A.—Hand follow-up circuit. B.—Hand control induction regulator motor. C.—Hand/auto changeover relay. et.—Terminal voltage. er.—Reference voltage. iAVR.—Regulator control output signal = K (er − et). iH.—Hand control signal

Some informative results have been obtained from an extensive series of tests recently carried out on a regulator of this type controlling a 60 MW direct-cooled turboalternator installed by the G. E. C. in the Poole generating station of the Southern Division of the Central Electricity Generating Board. Many synchronous and asynchronous running tests were made to examine the behaviour of the regulator under different conditions and to check its performance under rotor angle control instead of terminal voltage control. The opportunity was also taken to obtain data on machine characteristics not normally available, such as the measurement of the quadrature-axis synchronous reactance, running the machine as an induction generator with several field circuit connections, and performance under conditions of coarse synchronising. Analysis of the many oscillographic records will take some time, but it is possible to make some preliminary comments on a few of the more interesting results.

The response of the excitation system to a sudden change of voltage setting is shown in Fig. 2, where the change of signal was such as to alter the generation from 60 MW unity power factor to 60 MW, 45 MVA lag (i.e. 0.8 p.f.). The reapid rise of the main exciter field current



	Initial Readings	Final Readings
MW	62·24	61·28
MVAr	10 lag.	43·6 lag.
Stator voltage	11·2 kV	12·3 kV
Stator current	3,209 A	3,563 A
Load angle	66 deg	40 deg

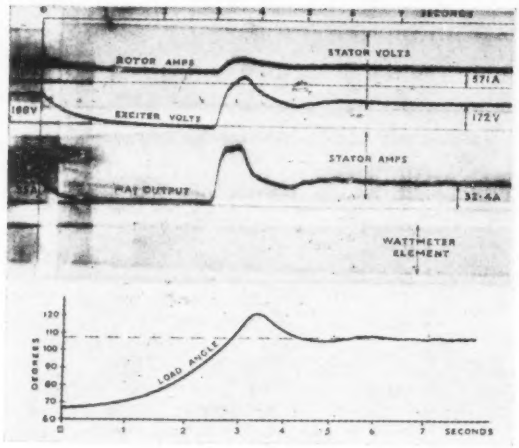
Fig. 2.—Transient step change of regulator voltage setting

indicates clearly the high performance obtained from the 400 c/s magnetic amplifier chain. The terminal voltage reached its final value well within 2 sec. The initial dip in the terminal voltage trace was caused by a change of sensitivity applied to this trace as an indication of the instant when the transient kick was applied to the regulator.

ROTOR ANGLE LIMIT CONTROL

The rotor angle limiter is a continuosly acting device whose operation may be considered equivalent to that of a stiff spring-loaded buffer, so that if the rotor tends to move beyond the set angle a signal proportional to the excess angle is applied to the a.v.r. to boost the excitation and prevent further increase of angle. This was demonstrated with the unit on 60 MW by adjusting the rotor angle limiter to 70 deg and then reducing the a.v.r. setting until the rotor angle approached this value, when the limiter began to have some effect. The first action was to bring up the rotor angle alarm. Subsequent reduction of the a.v.r. setting down to the miniumum had little effect on the terminal voltage and rotor angle. The alternator excitation was now completely determined by the rotor angle limiter equipment and by altering the adjustment of the limiter, the alternator could be moved round to any load angle within the range of stable operation under normal a. v. r. control. In effect, this meant that the alternator was on rotor angle control instead of voltage control.

Tests were then conducted to determine the ability of the limiter to prevent a machine falling out of step under adverse transient conditions. One of these tests was to start with the alternator running at a normal load angle at 60 MW and suddenly to reduce drastically the a. v. r. setting giving a resultant zero field voltage on the alternator. Under these conditions the rotor angle limiter invariably provided a "buffer" to the rotor as it attempted to fall out of step and correctly held the machine on the limiter equipment. An example of this is shown in Fig. 3.



	Initial Readings	Final Readings
MW	61·2	61·04
MVAr	20·1 lead.	56·0 lead.
Stator voltage ..	13·0 kV	11·93 kV
Stator current ..	2,850 A	3,955 A
Load angle ..	66 deg	107·5 deg

Fig. 3.—Rotor angle limiter preventing instability after a sudden step reduction of the regulator voltage setting

A further interesting example of a practical application of this is shown in Fig 4. where the rotor angle limiter has prevented loss of synchronism due to the line switching disturbance described below. This demonstrates that if a set is running at a high angle near the stability limit, the rotor angle limiter can ensure that no adverse system switching will cause the machine to fall out of step. It will be noted that the final steadystate load angles of 107·5 deg in Fig. 3 and 109·5 deg in Fig. 4 are substantially beyond the earlier theoretical limit of 90 deg, i.e. well inside the dynamic stability region.

EFFECT OF LINE SWITCHING DISTURBANCE

A reactor was available which had a reactance equivalent to approximately 50 miles of 132 kV overhead line. Tests were made to study the response of the a. v. r. to sudden insertion and removal of this reactor in direct series with the generator-transformer unit. It was found that when the alternator was running on a. v. r. control at a high machine angle, the sudden insertion of the reactor led to a reduced angle of generation and a greater stability margin and, conversely, the sudden short-circuiting of the reactor caused an increase in the angle of generation and loss of stability if the initial angle was too high. This is directly contrary to the known effect on normal hand-excitation control.

Tests were made, starting at 100 deg rotor angle generating 60 MW with the reactor in circuit and then shorting out the reactor with and without the rotor angle limiter in service. With no limiter, the set immediately fell out of step and resulted in the most

severe system disturbance experienced during the whole series of tests. With the limiter in operation, stability was easily maintained as mentioned earlier with reference to Fig. 4.

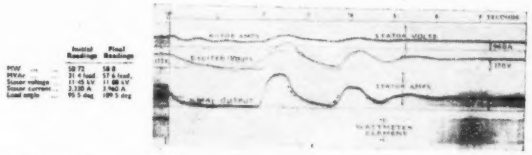


Fig. 4.—Rotor angle limiter preventing instability after line switching disturbance

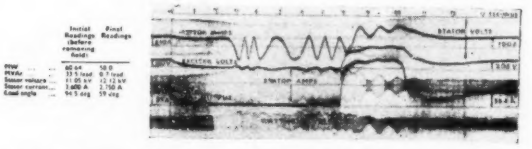


Fig. 5.—Restoration of synchronism by switching to a.v.r. control after removal of field at 60 MW

Completely stable operation was obtained when generating 60 MW, 66 MVAr lead at a terminal voltage of 11·25 kV. This gave a transmission angle between the direct axis of the machine and the 132 kV station bars of 120 deg, representing a steady-state limit well beyond that likely to be required in practice. The addition of ±5 per cent current compounding caused a variation of ±3 deg in the absolute stability limit.

SYNCHRONISING ON A. V. R. CONTROL

Tests were made to determine how the machine would pull back into step on a. v. r. control once pole slipping had started. To do this the automatic hand control follow-up equipment was disconnected, and the hand control induction regulator moved to the zero field position while the set was running on a. v. r. control. To initiate the test, the machine was switched to hand control resulting in zero alternator field voltage. After several seconds of pole slipping the set was restored to a. v. r. control when invariably the machne pulled back into step even on 60 MW governor setting.

The main reason for this is that during pole slipping the terminal voltage drops so low that the a. v. r. receives a continous signal for peak forcing excitation. This produces a powerful resynchronising effect, the result being clearly seen from the oscillogram in Fig. 5. The addition of the extra series reactor did not alter this performance.

FIELD SWITCH OPENING ON LOAD

Tests were made by running the set on hand control at various power loads at unity power facter, opening the main field switch and reclosing it several seconds later. Results showed that up to 45 MW, resynchronising took place without altering the excitation setting, but above this figure an increase was necesary to pull the machine back into step. This applied generally to

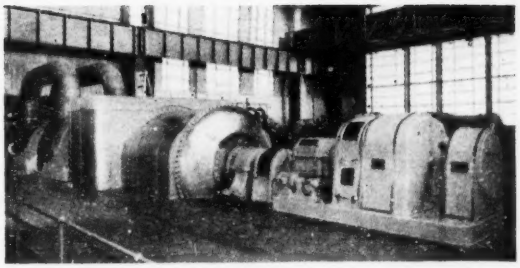


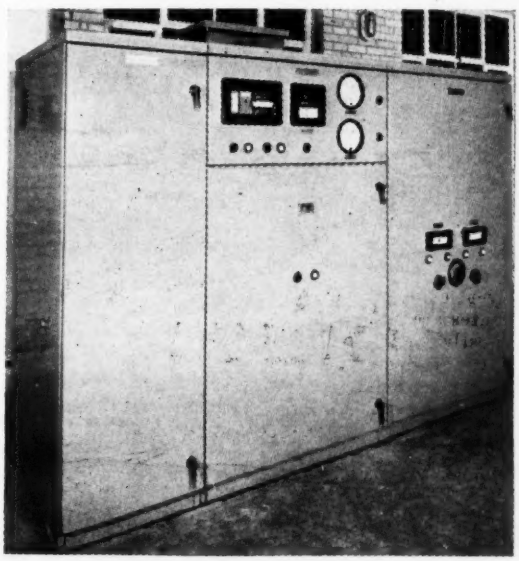
Fig. 6. View of the extensions at Poole shoing the G.E.C. 60 MW set on which the tests were made.

tests with and without the field discharge resistance in circuit and also with and the without extra series reactor.

The alternator is a 60 MW machine with direct rotor cooling and the first to be commissioned in Britain designed to operate at a hydrogen pressure of 30 p.s. i. The physical size of the unit is much smaller than that of a conventionally cooled machine of the same rating. The gear-driven exciter runs at 1.000 r. p. m. with an overhung 400 c/s homopolar alternator to supply the a. v. r. equipment. Since there is no other rotating plant the total amount of brushgear is reduced to the minimum of the exciter armature and the alternator rotor slip rings.

The voltage regulator is a type C. V. R. 7 magnetic amplifier continuously acting regulator employing a double neon reference tube circuit for high reliability and accuracy. The voltage error is amplified by two primary amplifier stages and controls a final magnetic amplifier of 12 kW peak output for supplying the field of the main exciter. The overall gain is such that

Fig. 7.—Combined a.v.r. and field suppression cubicle



the terminal voltage is regulated within 0.5 per cent of the set value. A fixed negative bias field is supplied to the exciter to improve the voltage bucking performance of the equipment.

The rotor angle limiter type K. A. L., incorporated as a standard feature, receives its signal from a permanent magnet alternator on the shaft, so that an accurate indication of the rotor angle is obtained both during steady state and transient conditions. Once the set rotor angle has been exceeded, a strong boosting signal proportional to the excess angle is applied to the amplifier chain of sufficient gain to convert the equipment virtually into a rotor angle controller.

On hand control an induction regulator is used to adjust the signal winding of the main magnetic amplifier. On automatic control, the same regulator follows up the a. v. r. excitation settting so that a rapid changeover back to hand control can always be made without disturbance.

The over-riding principle has been to design a static regulator system with the greatest simplicity and reliability.

MEASUREMENTS AND RECORDINGS

Oscillographic records were taken of machine terminal voltage, stator currents, MW and MVAr output, rotor current, exciter voltage and field current, rotor angle speed, governor travel and input steam pressure. The initial and final values of most of these quantities were recorded by sub-standard instruments specially calibrated and installed for the tests by the Metering Section of the Technical Department of the Southern Division.

The rotor anagle indicating instrument installed in the control room, and forming part of the normal a.v.r. equipment, is scaled 0-160 deg. A second instrument was provided to indicate the overall transmission angle between the rotor and the 132 kV busbars, and both meters agreed in general to within I deg with readings taken by stroboscopic shaft equipment. This equipment, developed and operated by the London Division of the C. E. G. B., provided recordings and a running commentary which considerably facilitated the control of many of the tests.

Altogether over 70 tests were made during the week, and a great proportion required initial and final readings, plus a transient record. Full evaluation of the records will give valuable new insight into the performance of synchronus machines under many unusual conditions and methods of control

Acknowledgements is due to the C.E.G.B. for permission to carry out the tests and making all the necessary system preparations and protective gear setting arrangements, and also the Messrs. Merz & McLellan for their assistance.

Courtesy: Electrical Review

[*Continued from page 11*

Current Developments in Nuclear Power in Britain

Since the power required for marine propulsion is low—20,000 or 30,000 H. P.—the development of such nuclear plant will naturally pave the way for small, package land power stations that are competitive with coal—or oil-fired ones in many parts of the world. So far, the "nationalized effort" has hardly been directed at all towards the development of these small land stations and it is for this reason that industry has been "going it alone" in this field, or else turning towards America for assistance.

CONCLUSION

During the past year or so, the impression has been growing in Europe and elsewhere that nuclear power is not competitive with conventional power and it would be as well for countries that are contemplating embarking upon a nuclear power programme to postpone their efforts. Circumstances are, of course, very different in different countries. In America, interest rates are high and conventional fuels are plentiful and therefore cheap. There, nuclear power is not yet even nearly competitive. Elsewhere, interest rates are high but conventional fuels are scarce and costly; here, nuclear power approaches competitiveness. In Britain, interest rates are low and the cost of conventional fuels is on the low side too, though not as low as in America; nevertheless, circumstances are such as to put the cost of nuclear power within about 10% of that of conventional. In addition, the magnitude of the nationalized electricity network in Britain—about 25,000 MW—is such as to permit the installation of large units of 250 MWE without having "to many eggs in one basket"; and with the technology where it is at the moment, the larger the plant the more nearly does it approach competitive economy.

In spite of this prevailing pessimism, there is unanimous agreement that nuclear power is the ultimate solution to the world's power problems and that its application on a wide scale, and in most countries, will be imperative in the 1970's. The 1955 British Programme of Nuclear Power predicted that it might be possible, perhaps even essential, in the "early 1970's" for only nuclear power plant to be installed, since by that time there would be in operation so much coal- and oil-fired plant as to require all the conventional fuel likely to be available for electricity generation at that time. How would it be at all possible to install only nuclear power plant in the "early 1970's" if there were no industry geared-up to meet the critical requirements of such plant? It is now seven years since the heavy engineering industry in Britain first embarked upon major construction in the field of atomic power and, although some of the manufacturing works involved were the largest of their kind in the world, these would be the first to admit that they had not yet reached satisfactory solutions to the many difficult fabrication problems that have arisen. It is apparent that it will have taken not less that 10 years to "gear-up" the workshops to meet the nuclear challenge but, having achieved this, the background will be adequately available to undertake in earnest the arduous burdens of the impending nuclear era.

A Paper read before a Studo Conference on Nuclear Energy, organized as a Joint Meeting of S.I.A. (Swiss Association of Engineers and Architects) and S.V.A. (Swiss Nuclear Energy Society) held in Zurich, 24/26 March, 1960.

High Marnham Power Station

The erection of the High Marnham power station in the East Midlands Division of the Central Electricity Generating Board represents a great construction feat. The ultimate station generating capacity will be 1,000 MW in five 200 MW generating units each with its self-contained boiler. The first of these units has been put into commission in 1959, a little more than two years after the commencement of work on the site.

One of the major projects of the Central Electricity Generating Board is the construction of a new 1,000 MW steam generating station in the operating area of the East Midlands Division. The station is within easy reach of the East Midlands coal fields and is situated on the west bank of the River Trent adjacent to the main railway line connecting Chesterfield and Mansfield with Lincoln.

The site is situated roughly at the centre of the triangle formed by Newark, Lincoln and Retford. The area surrounding the site is mainly agricultural and due consideration of this feature has been made in the restriction of the site area, the planning of the site layout and the building construction. The development of the site has involved the building of a construction camp and the provision of water and electricity supplies to the area and has required some improvements to the minor road approaches.

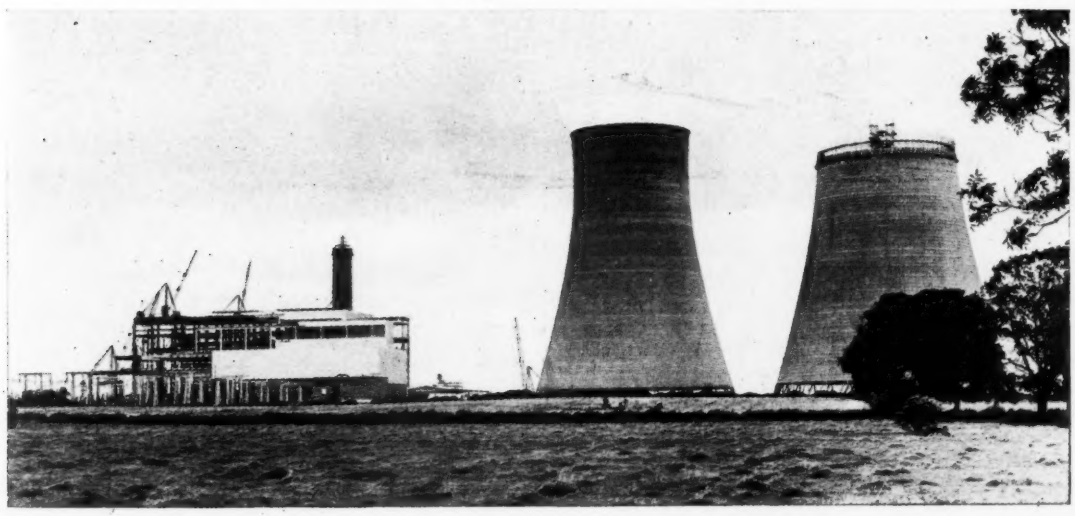
The main building will house five 200 MW generating units arranged longitudinally in an east to west direction giving a southern aspect to the exterior wall of the turbine house. The west gable of the main building is seen from the road approach the station whilst the view of the east gable from across the River Trent is screened by the five cooling towers which are arranged in double triangle formation.

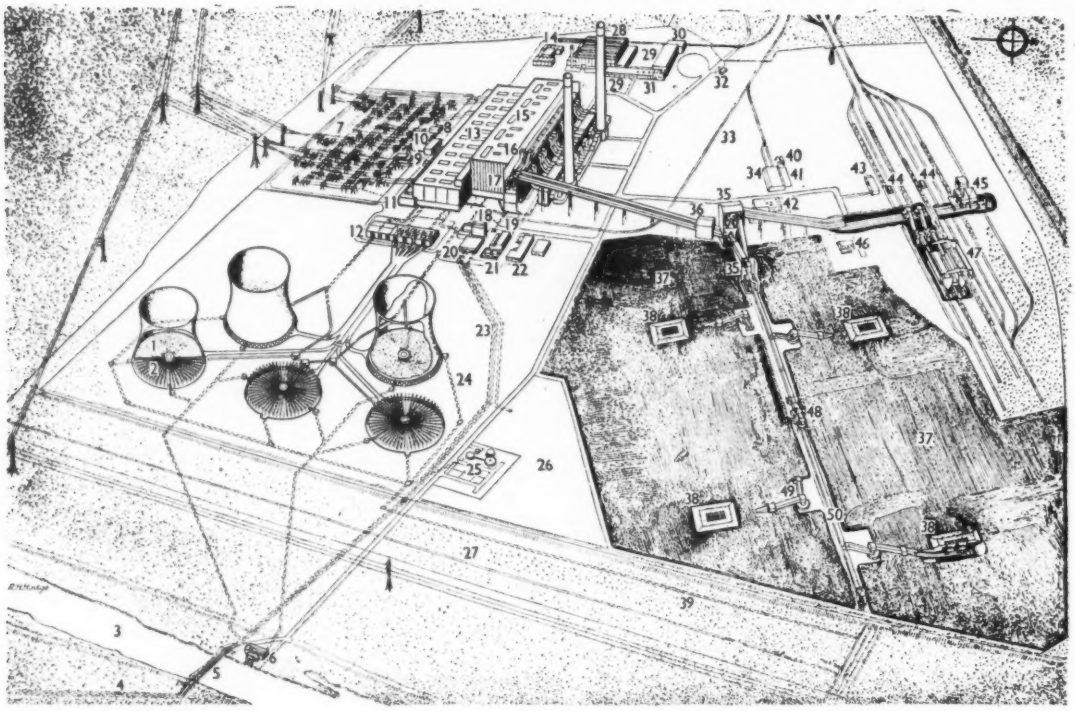
The coal sidings form the northern boundary of the site and lie parallel with the main railway line. The administration buildings are arranged on the approach road to the main building and comprise offices, canteen and workshops. Two of the predominant features of the main structures of the station are the twin concrete chimneys each 450 ft in height and the five 340 ft high cooling towers. The latter have been constructed with a khaki coloured cement which gives a pleasing effect when viewed against the general background.

Separate ancillary buildings for circulating water, water treatment, oil fuel and ash plant are situated between the cooling towers and the east gable of the main building. The 275 kV outdoor switch compound is situated south of the main building and in a parallel formation to the line of the generating units. The pump house for extraction of make-up water for the circulating system is on the west bank of the River Trent and a road viaduct has been constructed to maintain access over the washland when the river is in flood. The existing floodbank has been increased in height to ensure that the power station area shall be adequately protected from flooding under the worst known conditions of tide and elements.

To ensure that the site drainage will be maintained

The Station building from the South-East





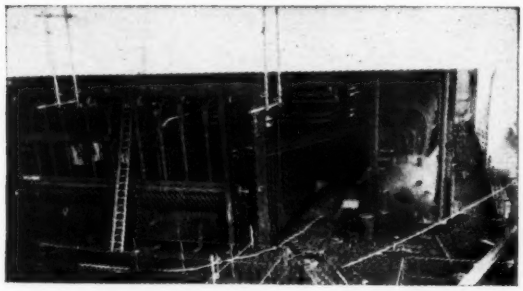
The arrangement of the High Marnham Generating Station: 1. Eliminator pack; 2. Water distribution pipes; 3. River Trent; 4. Dust pipes to gravel pits. 5. Foot and pipe bridge; 6. Make-up pump house; 7. 275 kV switch compound; 8. Switch compound oil plant; 9. Relay building; 10. Chlorination plant; 11. Station control room; 12. Circulating water pump house; 13. Turbine house; 14. Garage, oil and paint stores; 15. Boiler house; 16. Bunker conveyor; 17. Conveyor junction tower; 18. Dust hopper; 19. Substation, 20. Ash plant pump house; 21. Oil plant; 22. Water treatment plant; 23. Dust pipes; 24. Purge pipe. 25. Sewage purification plant; 26. Emergency ash lagoon; 27. Drainage channel; 28. Workshops and stores; 29. Offices; 30. Laboratory; 31. Canteen. 32. Gate house and road weighbridge; 33. Railway line to turbine house; 34. Locomotive shed; 35. Junction tower; 36. Weigher house; 37. Coal stockpile; 38. Reclaiming ground hoppers; 39. Purge pipe; 40. Fuel tanks; 41. Bulldozer shed; 42. Coal plant control; 43. Coal sidings substation; 44. Railway weighbridges; 45. Tippler; 46. Surface water pump house; 47. Track hoppers; 48. Travelling tripper; 49. Conveyor lifted during stocking out; 50. Reversible conveyor

during river flood conditions a drainage pump house has been constructed within the station boundary. A further feature of the river works has been the construction of a 276 ft span suspension bridge to carry the dust pumping lines across the River Trent. Advantage has been taken of this feature to provide a walkway over the river to facilitate the journey of station staff who may live in the villages on the east bank of the river. Disposal of ash from the station will be by pipeline in the case of pulverised fuel dust and fine furnace ash, and by road transport for coarse furnace bottom ash.

The foundation works for the main building structure comprise a deep raft section for the turbine house containing circulating water aqueducts, drainage and cable pipes, etc., with individual pile caps for the main columns in the boiler house. The loads on the boiler house columns vary from 500 to 1,500 tons per column. Each chimney has an octagonal pile cap bearing on 269 cast-in-situ piles of an average length of 20 ft. The whole of the inside of the chimney is lined with acid-resisting brickwork and, in addition, the top section is formed wholly of brickwork anchored to the reinforced concrete shell by pre-stressed rods. The foundations for the cooling towers, coal and ash plant and ancillary buildings are of the raft type with individual footings where required. The turbo alternator foundation blocks have overall dimensions of 104ft long by 37ft wide including the overhung platform and the top of the block is 35 ft above the turbine house basement level. The blocks are formed of concrete pre-stressed longitudinally, transversely, and vertically on the Freysinnet and Macalloy systems. The construction of the block is sectionalised to minimise shrinkage and creep movements.

The main building structure is designed round a steel framework, the main members of which are of mild steel welded box formation giving a very clean appearance. Plated girders are used for intermediate connections. The total weight of steelwork in the main building structure is 15,200 tons and high tensile steel grip bolts have been used for all connections subject to stress reversal. The coal bunkers are constructed of steel plate and are designed on the stressed-skin principle. The midspan joints of the turbine house roof girders are site welded. The intermediate floors of the main buildings are of reinforced concrete open steel grid or non-slip steel plate. Certain sections of the turbine house operating floor will be finished with tiling.

The cladding of the main building is of reinforced concrete walling faced with exposed aggragate slabs



The steam/water drum of the circulating system at the top of the first boiler

using Criggion grey-green granite chips inserted on the gable ends up to 43 ft above ground level. The remaining section of the main building is clad with pressed aluminium alloy wall panels and suitably glazed. The aluminium sheeting to the turbine house section will have an integral thermal insulation lining. The roof of the main building will be formed of pressed sheet steel decking, insulated and waterproofed, and completely hidden by a parapet extension of the wall cladding. The combination of the aluminium sheeting, glazing and greenish tinged concrete slabs is such as to give a well-blended effect.

The precipitators are constructed of natural coloured concrete. The ancillary buildings will be mainly covered with light brown sand-faced bricks, but part of the circulating water pump house and all the coal conveyors will hve aluminium cladding.

The turbine house is arranged with the turbo-alternators in longitudinal line on 120 ft centres with the steam end of each set to the west. H.p. and l.p. heaters are situated in line parallel to the machine and on the side nearest the boiler house. A bled steam evaporator is installed adjacent to each heater group. The boiler feed pumps are situated in the turbine house basement to facilitate handling by the turbine house cranes. The booster feed pumps are in the basement of the control annexe between the turbine house and boiler house. Two 100 ft span cranes are installed in the turbine house, the largest having a lifting capacity of 168 tons, this being the weight of the maximum lift, which is the alternator stator.

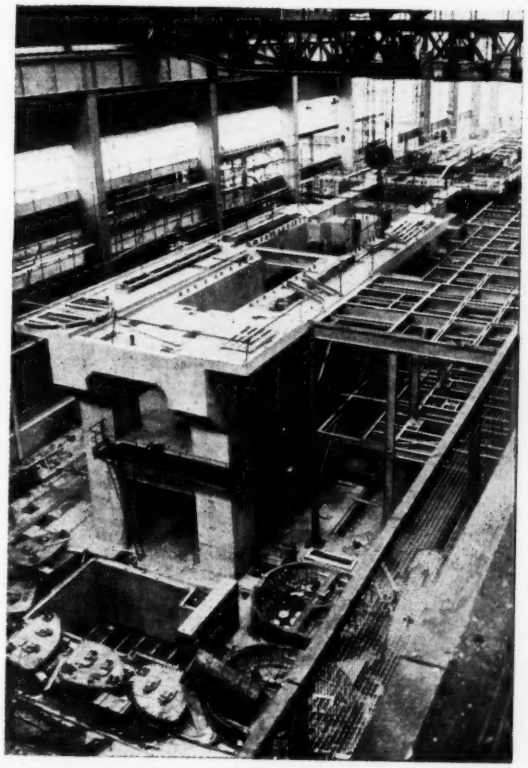
The twin furnace boilers are arranged in longitudinal line consecutive with the turbines, the bunker bay and coal milling plant being situated on the north side of the boiler house and away from the turbine house. Access to the various levels of the boiler house is provided by three lifts and four stair wells which are situated between the respective units and are also adjacent to the control annexe.

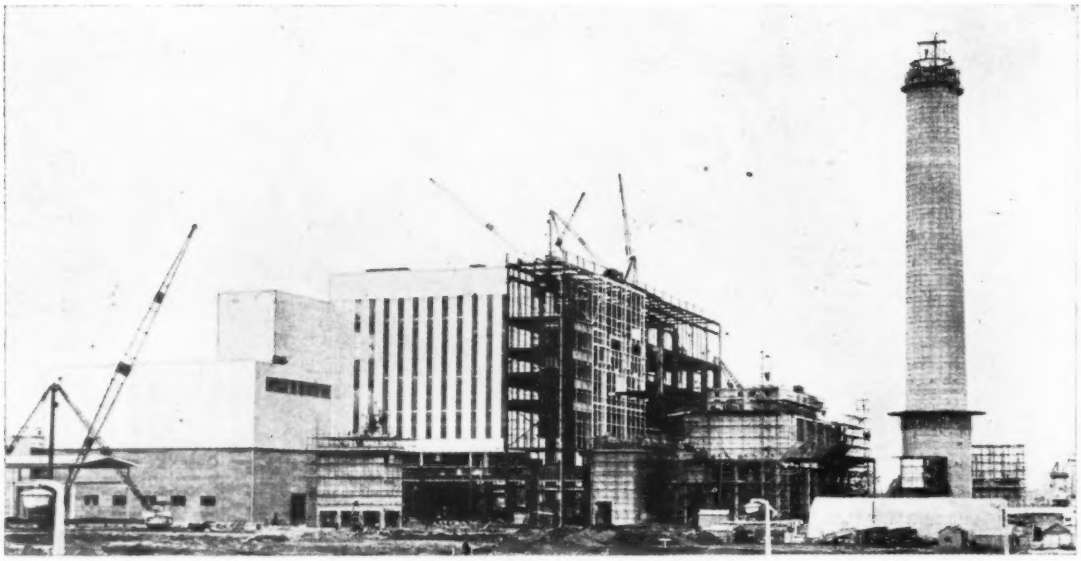
The unit control annexe is between the turbine house and boiler house and on the various levels contains the control rooms, de-aerators, reserve feed tanks, etc., associated with each unit. Five sections of the annexe are devoted to pipe shafts for the interconnecting pipework between the turbines and boilers. An annexe on the south side of the turbine use is provided to accommodate the auxiliary switchgear associated with the unit and common station services. The eastern part of this annexe forms the main station control room and station battery rooms. There are various offices for operating staff at the operating floor level in the turbine house annexe. An annexe is also provided on the north side of the boiler house for the electrical equipment associated with boiler plant.

Certain items of main plant connected with the units are out of doors; they are the generator main and auxiliary transformers, electrostatic precipitators and induced draught fans. The generator transformers are sited south of the turbine house and are connected to the main switchgear compound by overhead 275 kV lines, the ends of which are supported from the turbine house structural steel. The twin banks of precipitators and induced draught fans are arranged in unit formation between the boiler house and the chimneys; in this area are also situated the dust pump houses and vacuum cleaning plant associated with each unit.

The forced draught fans are situated above the coal bunkers at a height of 118 ft above the boiler house

The turbine line showing the completed block for No. 1 set in the foreground





Another view of the Power House under construction

basement and a crane has been provided for the maintenance of the fans and for lowering sections to ground level. The general layout of the boiler house and turbine house has been designed on the unit principle to facilitate erection, making each unit operationally identical.

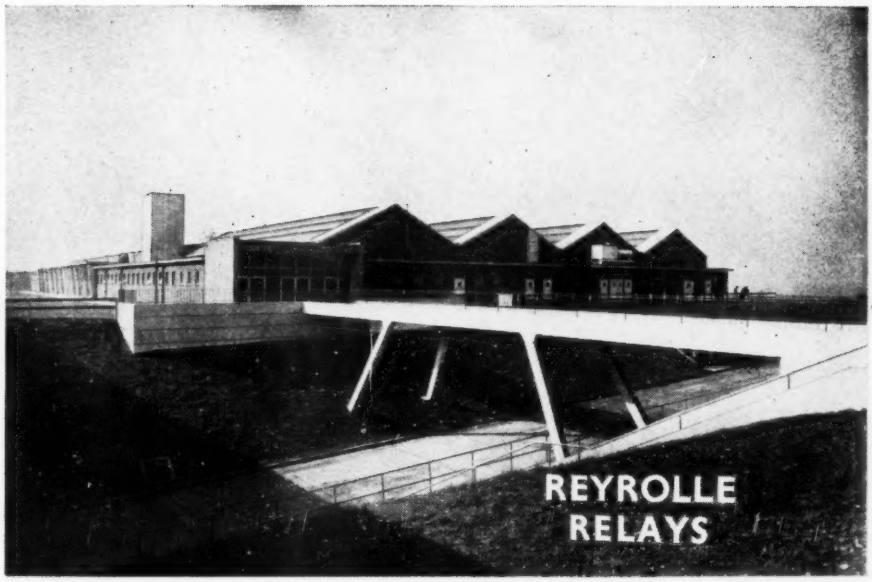
The radiant type boilers have been designed to burn untreated smalls and washed smalls obtained from the East Midlands Division of the National Coal Board and the rate of evaporation is 1,400,000 lb/hr for Nos. 1, 2 and 3 boilers and 1,350,000 lb/hr for Nos. 4 and 5 boilers at continuous maximum rating. The conditions of operation are such that steam will leave the superheater at a pressure of 2,450 p.s.i. and a temperature of 1,060 deg F. The steam will return from the turbine to the reheater at a pressure of 476 p.s.i. and with a temperature of 667 deg F The reheater outlet steam temperature will be 1,005 deg F.

The boilers have separate superheat and reheat furnaces with all pressure parts slung from the main building overhead steelwork. The furnaces are fully cooled, corner fired, and an assisted circulation system is employed to ensure a positive circulation through the furnace system. The unit is arranged with two similar furnaces connected on the steam and water side in parallel with a common steam drum via downcomers, circulating pumps and distributing drums at the bottom of the furnaces. The furnaces are described as "superheater" and "reheater" as characterised by the situation of the secondary superheater at the exit of the one and the reheater at the exit of the other. Similar primary connections, and radiant superheater stages an installed in both furnaces. The furance is completely water cooled below rear wall arch level and, in the main, is steam cooled above this level. An entirely new type of casing has been adopte. This is of the skin-cased cubic expansion design which prevents deterioration of the insulation by the elimination of gas leakage from the furnace.

The gas and air ducting connections to the furnaces are such that one induced draught fan and one forced draught fan are normally associated with each furnace, but it is possible, by the use of dampers, to connect a single fan of eithr type to both furnaces. The air is drawn from the upper part of the boiler house to conserve the radiated heat and to assist the boiler house ventilation.

A welded economiser and a rotary air heater are situated at the rear of each furnace above operating level. Two secondary air heaters provide a supply of hot air to the coal pulverising mills. The furnaces are started upon oil fuel and normal firing is by pulverised coal. Six mills are installed for each boiler, their capacity being such that with the normal fuel four mills will be sufficient to meet full load on the boiler. The arrangement of fuel piping permits three mills to feed each furnace independently, but a crossover device enables either of the two centre mills to be connected to either furnace. The latter arrangement ensures extra availability during times of maintenance on individual mills.

Each furnace is fitted with sixteen pulverised fuel burners, four at each corner to give tangential firing. The burners are of the tilting type to give control of the temperature of the steam leaving the superheater and reheater. Spray desuperheaters are connected in the steam lines as an emergency control to maintain the steam temperature at a safe level during abnormal operating priods.



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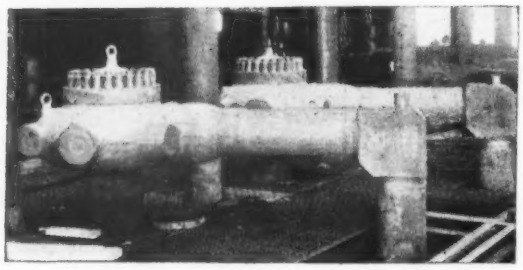
Looking up inside the first cooling tower, 340 ft high and 260 ft maximum diameter ; note slender supports for shell

Duplicate pairs of 100 per cent capacity multi-stage boiler feed and booster pumps are installed for each unit. They are electrically driven and the combined h. p. of the motors driving each main pump and booster pump unit is 7,725 h. p. Both motors are direct-on started and are controlled by a single 6.6 kV circuit-breaker. Each main and booster pump is fitted with a flow controlled "leakoff" and, in addition, each main pump is fitted with an automatic thermal "leak-off" arranged to operate in the event of the feed water exceeding a predetermined temperature.

The 200 MW turbo-alternators have tandem three-cylinder impulse reaction turbines designed for steam conditions of 2,350 p.s.i. and 1,050 deg F at the h.p. inlet valve and 475 p.s.i. and 1,000 deg F at the i.p. inlet valve. The difference between these conditions and those quoted for the boiler are accounted for by the losses in the pipework. The nominal speed of the turbine is 3,000 r.p.m. and the unit is designed to

The four boiler circulating pumps, without drives but with testing plates, for the first unit



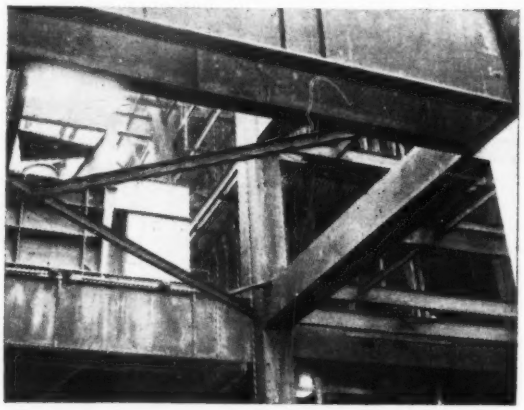
Line of hoppers feeding down from the coal bunkers

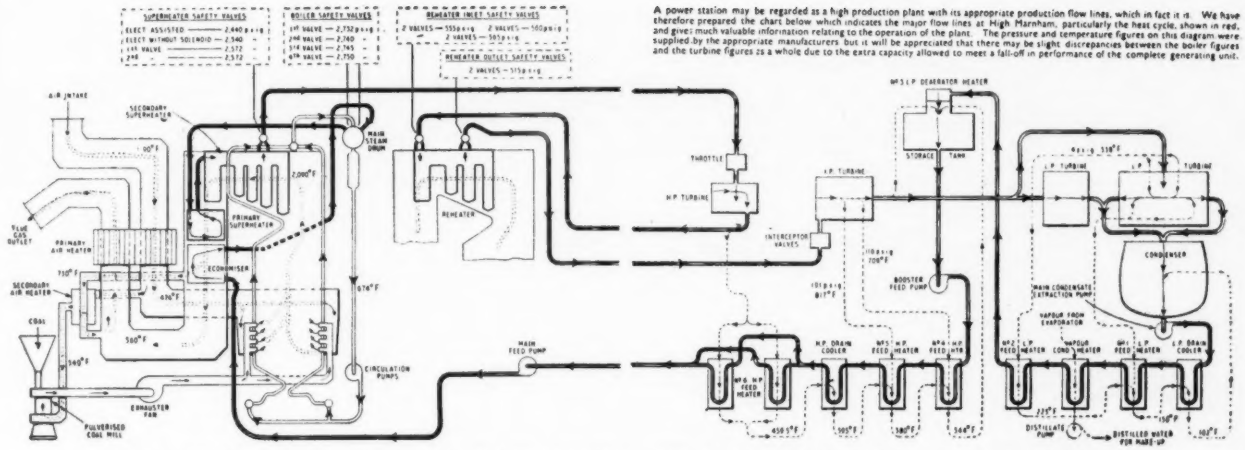
give its 200 MW output as the most economical and continuous maximum rating at 0.9 lagging power factor. Feed water is heated to a maximum temperature of 460 deg F and feed water de-aeration plant has been included with the provision for off-load de-aeration.

The turbine is fitted with a single shell condenser designed to give an exhaust pressure of 1.3 in Hg (0.64 p.s.i.a.) at c.m.r. when using cooling water at a design temperature of 60 deg. F. Mechanical type air extraction pumps are provided for normal running and for quick starting. Other turbine auxiliary plant is of the conventional type but suitably rated for the larger machine.

Each alternator will have a terminal voltage of 16.5 kV and a rated phase current of 7,780 A at 0.9 power factor. The stator and rotor have tubular conductors directly cooled by hydrogen at a pressure of 30 p.s.i. circulated by blowers gear driven from the main shaft.

Looking up at the rotary air heater and a section of the economiser on the right, from the control level





A power station may be regarded as a high production plant with its appropriate production flow lines, which in fact it is. We have therefore prepared the chart below which indicates the major flow lines at High Marnham, particularly the heat cycle, shown in red, and gives much valuable information relating to the operation of the plant. The pressure and temperature figures on this diagram were supplied by the appropriate manufacturers but it will be appreciated that there may be slight discrepancies between the boiler figures and the turbine figures as a whole due to the extra capacity allowed to meet a fall-off in performance of the complete generating unit.

Pilot and main exciters are also gear driven from the main shaft. The maximum output of the main exciter is 3,000 A at a rated voltage of 520 V; the speed of the exciters is 750 r.p.m. The weight of the the complete turbo-alternator set is 1,450 tons.

OPERATIONAL DETAILS

Oil for boiler lighting-up purposes is transported to the station by road tanker and stored on the site in two 150 ton capacity oil tanks. The oil is heated and pumped round a circulating main and is tapped off at each boiler. After boost heating it is sprayed into the furnace by burners which are electrically ignited, thus creating the required conditions for commencement of coal firing. When coal firing has been stabilised the oil burners are taken out of service.

Coal is transported by rail from the East Midlands coalfields at the rate of 10,000 tons per day. The daily delivery to the site requires twelve trains, each of 34 wagons, each containing 24½ tons of coal. One reception track and fourteen exchange sidings are provided and four locomotives are required on the site to complete the process of emptying the wagons and returning them to the sidings. The wagons are of the bottom discharge type and will deposit the coal into a ground hopper from which it is transported by conveyors either to the bunkers in the boiler house or to the station stockpile. Weighing and sampling equipment is installed for checking quantity and grade as the fuel is delivered. Coal is deposited and reclaimed by a single reversible conveyor with a delivery capacity of 1,000 tons/hr. Distribution and reclamation of the stockpile are carried out by bulldozer operations. A twin line of conveyors connects the railway ground hopper with the bunkers: each conveyor has a capacity of 500 tons/hr. The coal is screened, crushed, weighed and sampled, and all magnetic material is extracted on the journey to the bunkers.

The boiler house bunkers have a total capacity of 11,500 tons. Six bunker outlets are connected to each boiler. The coal leaving each bunker outlet is automatically weighed and delivered by chute to the coal mill, is dried by hot air tapped from the furnace air supply, and after grinding to a predetermined grade of fineness is exhausted from the mill. The air/fuel mixture is then fed into the furnace via the corner burners and ignited.

Coarse ash is collected in a hopper below each furnace and is periodically sluiced by a high-pressure jet system into a sump at the east of the main building. The sump is fitted with screens which retain the coarse furance bottom ash, but allow fine particles to pass out into a dust sump. The coarse ash is removed from the sump by means of a grabbing crane and is taken from the site by road transport. Dust collected from the flue gases by mechanical and electrostatic precipitators is transmitted by means of fluidising conveyors from hoppers on the precipitators to a unit buffer hopper and, in a dry condition, it is pumped to a large storage bunker. There is facility to draw on this bunker for supplies of dust for use in constructional work, but such requirements are comparatively very small.

The dust is then extracted from the storage bunker by rotary feeders and conveyors, and, in a conditioned state, it is deposited into a sluice feedng into the dust sump. The wet dust is collected from the dust sump by slurry pumps which pump the wet mixture through pipelines over the River Trent to a disposal area about 5¼ miles away. The wet dust pipes to the disposal area are of 15.3 in internal diameter and the quantity of dust disposed of in this way each day when the station is on full load is approximately a,1,500 tons.

COMBUSTION CIRCUIT AND HEAT CYCLE

The air and gas flows through each of the two furnaces normally follow parallel paths from the air intakes to the main flue. The air is drawn from the upper region of the boiler house by the forced draught fans and fed through rotary air heaters into the furnaces at the four corners and adjacent to the fuel inlets. The hot gas is drawn from the furnace by the induced draught fans via the economiser, the rotary air heaters, and the mechanical and electrostatic dust

Upward view of the superheat furnace from basement level looking upwards towards boiler circulating water system

precipitation; then, having passed through the induced draught fans, it is led into the main flue and thence to the chimneys. Hot gas is tapped from the main stream to heat a secondary air heater through which hot air is fed into the coal pulverising mills. There is provision for recirculating the hot gas through the furnaces to give a further facility for the control of furnace conditions. Television apparatus is installed to give the operating engineer a view of flame conditions in each furnace.

Condensate is extracted from the single shell condenser by either of two full-duty extraction pumps and thence to the boiler feed water heating system which is designed to raise the temperature of the feed water to 460 deg F by steam heaters and drain coolers. Steam for feed water heating purposes is bled from six points on the turbine. The feed water heating system consists of a low-pressure drain cooler, three l.p. heaters, three high-pressure heaters and a h.p. drain cooler. The l.p. heaters are on the suction side of the booster feed pumps and the h.p. heaters are interposed between the booster feed pumps and the main boiler feed pumps. The l.p. drain cooler and the first two l.p. heaters are of the vertical surface type, the third l.p. heater being arranged as an elevated de-aerator of the direct contact type. The three h.p. heaters and the h. p. drain cooler are also of the vertical surface pattern.

The de-aerator has a water storage capacity to provide at least ten minutes' running of the turbine at full load. Normal slight fluctuations in boiler demand are met from this capacity, but in the event of an abnormal demand additional water is drawn from the reserve feed tanks. In the event of abnormal decrease in feed water demand surplus water is supplied by the extraction pump to the reserve feed tanks. After discharge from the main boiler feed pumps the boiler feed water flow is regulated by two of three 50 per cent duty automatically controlled regulating valves and by two parallel connections fed via the two economisers into the common steam/water drum for the twin boiler furnaces.

Make-up water for each unit is provided by a bled steam single-effect evaporator. The make-up water is then passed through a demineralising plant and introduced into the feed water system at the condenser.

The steam flow is from the common steam/water drum, fitted with centrifugal separators, to the superheater sections of the boiler and twin pipe connections to two combined stop and emergency valves and after

passing through governing valves the steam is led into the turbine h. p. cylinder. Apart from some steam bled from the h.p. cylinder exhaust for feed water heating, all steam leaves the h.p. cylinder and is returned to the reheater section of the boiler. After reheating, the steam is returned to the turbine intermediate-pressure cylinder through twin interceptor and emergency stop valves.

The turbine intermediate-pressure cylinder is combined with one section of the three-flow l.p. cylinders and apart from steam bled for steam heating purposes, all steam is passed from the i.p. cylinder through the l.p. cylinder to the condenser, and the water is returned to the boiler feed water system, thus completing the heat cycle for the boiler-turbine unit.

CIRCULATING WATER

The cooling water sytem is arranged on the closed circuit principle with five cooling towers, each of sufficient capacity to meet the requirements of one generating unit. Make-up water is pumped continuously from the River Trent and a continuous purge system has been adopted to stabilise the quality of the water which would otherwise deteriorate becuase of losses by evaporation.

The towers are connected from the pond discharge point by open concrete ducts to a common suction dock outside the circulating water pump house. Five motor driven circulating water pumps are installed in the pump house, one associated electrically with each unit. The capacity of the pumps is such that two of them will meet the demand from three generating units. The five circulating water pumps are connected on the discharge side to a ring main which distributes the cooling water to the five generating units. For operational or maintenance purposes the distributing ring main can be sectionalised. The return water from the generating units is discharged into another ring main with separate branches to each cooling tower. The heated water is sprayed into the cooling towers and falls into the ponds at the base of the towers, thus completing the cooling water cycle.

Unit auxilary cooling water services are tapped off the large circulating water main at each unit. A chlorine injection system is installed for the prevention of the fouling of the condenser tubes; the chlorine is injected into the circulating water at the tapping-off point to each generating unit. The main circulating water ducts forming the two ring mains around the turbine house are for most of their length formed of 10 ft 6 in internal diameter miled steel pipes. River water for common station services such as bearing cooling, has sluicing and fire protection are extracted from the circulation water suction dock which is adjacent to the circulating water pump house.

ELECTRICAL SYSTEM

The generators supply electricity at 16·5 kV and each feeds into the 275 kV grid system through 210 MVA three-phase generator transformers with switching at 275 kV. Each unit has individual 17.5 MVA unit transformers rated at 16·5 kV/7·2 kV and auxiliary transformers rated at 6.6 kV/433 V. The auxiliary supply system is divided on the unit principle with interconnection between the station service system and the five unit systems at the 6.6 kV level only. Two large 240 V batteries are installed for the more important services and for the emergency lighting in the event of loss of supplies.

The electrical supplies for auxiliary power are at two levels of voltage: the larger motors are supplied at 6,600 V and the smaller ones at 415 V. The station supplies for starting-up purposes and for the common services are obtained from two 22.5 MVA, 275 kV/6.6 kV station transformers which are connected to the supergrid system.

ACKNOWLEDGEMENT

We are indebted to the Central Electricity Generating Board; International Combustion, Ltd.; the English Electric Co., Ltd.; Messrs. Freeman, Fox & Partners, civil consultants; and Messrs. Clifford Tee & Gale, architects, for their co-operation in the preparation of this article and the drawings.

(*Courtesy : Electrical Review*)

[*Continued from page 42*

550 MW Turbo-Generator Set

The turbines will have two governors; the main speed control governor is driven from the high-pressure turbine shaft and an auxiliary governor is driven from the first intarmediate-pressure turbine shaft. One governor is provided on each line of turbines and is mounted on a cross shaft driven through a worm and wheel.

Arrangements are made to extract steam from the turbine at seven pressure points to heat the condensate returning to the boiler, to a temperature of 486 deg. Fah.

To ensure uniform heating and cooling of the four turbine spindles and generator rotor on each line, when starting up or shutting down the machine, motor-driven rolling gears are to be provided. With these gears the machine can be kept slowly turning after being shut down, so that distortion due to unequal temperature distribution is avoided. Steam from the eight exhausts is to be dealt with by four condensers with a total cooling surface of 330,000 square feet.

The generators will operate at 18 kV, 0.85 p.f., 50 c/s at the design speed of 3000 r.p.m. The rotors are to be direct-gas-cooled, operating in hydrogen at a pressure of 45 lb per square inch. Each stator will have a direct-cooled winding, using demineralised water as the cooling medium circulating through the conductors, which will be built up of hollow rectangular copper tubes.

Excitation for each generator is to be provided by a main and pilot exciter driven from the generator rotor shaft through reduction gearing. Ventilation of the exciters is by the circulation of air round a closed circuit by a blower mounted on the pinion of the gear drive to the main exciter shaft.

(*Courtesy: The Engineer*)

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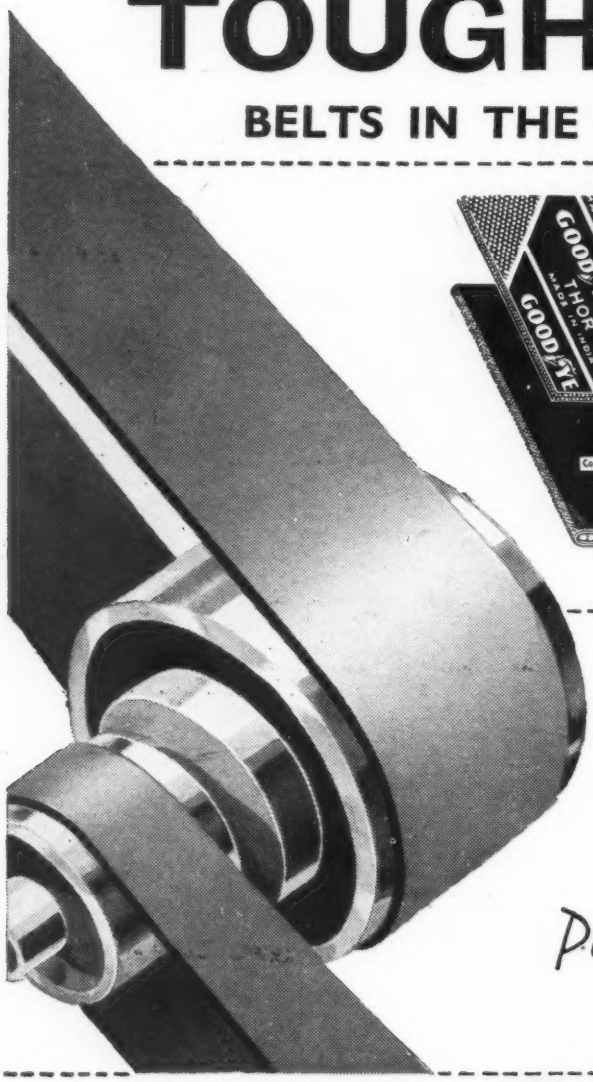

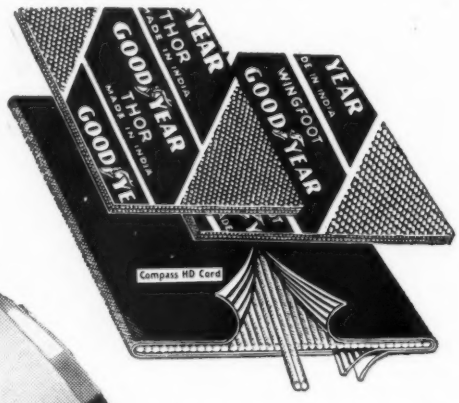

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High-Voltage Laboratory for Power Cables

A high-voltage laboratory has been set up to form an integral part of the new power cable works by British Insulated Callender's Cables, Ltd., at Erith, Kent. All the development and proving tests required by the power cable division will be concentrated at Erith in the new laboratory. The test equipment includes a 3.2 MV impulse generator, a smaller impulse generator and an 800 kV power frequency test set consisting of two 400 kV transformers with controlled series resonance. Present and future requirements for tests on power cables operating at 400 kV and above are well within the capacity of the laboratory.

With the setting up of the power cables division of B.I.C.C. in 1955, it was decided to reorganise the cable-making activities of the company and concentrate the manufacture of power cables at Erith, Kent. Subsequently a development programme involving the rebuilding of the power cable works at Erith was put in hand. An important part of this development is the new high-voltage laboratory which is described and illustrated here and is now in operation.

As an integral part of the new cable works, this laboratory is equipped for development tests and proving tests on power cables up to 400 kV. The new laboratory, with its improved facilities, has more than enough capacity to handle all the power cable testing work formerly done at the two B.I.C.C. laboratories at Prescot and Wood Lane. The Prescot laboratory has been closed and the high-voltage test equipment at Wood Lane (which has hitherto been much used by the company's power cable division) will now be available exclusively for other research work particularly on materials.

The major items of new plant in the laboratory are a 3.2 MV impulse generator and an 800 kV a.c. testing set; the space required for these items and, in particular, clearances to walls and roof, was one of the major factors in determining the size of the building. Items of subsidiary equipment include two 200 kV transformer test sets and a 640 kV impulse generator. Soon this generator will be extended to 1280 kV and a 76 kV three-phase a.c. test set will be installed.

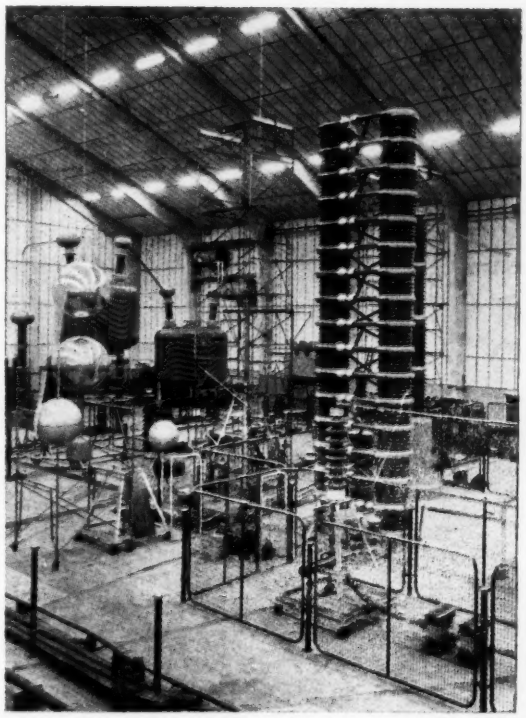
THE LABORATORY BUILDING

The building is 200 ft long and 108 ft wide and rises to a height of 58 ft to the apex and 37 ft to the eaves. To arrange this structure and its heavy equipment on a marshy Thamesside site posed problems which were solved by using a system of reinforced concrete piles (sunk to depths of 26 ft in some instances) over the whole area occupied by the laboratory.

Portal frame construction was used for the main hall of the laboratory which has an unobstructed floor area (22,000 square feet) which is thought to be as large as that of any high-voltage laboratory in the world. There are no cranes in the building because the provision of interlocks and observation of high-voltage clearances would seriously restrict their operation. All lifting is done from a standardised form of frame scaffolding and lifting beam arrangement which can be rapidly erected to any required height. An example of frame scaffolding can be seen in Fig. 1. The roof frame carries a number of support points for suspending high-voltage busbars.

Reinforced concrete, clad in double-skin asbestos with surrounding dado walls of brick, forms the main frame of the building. An infill of fibre-glass mat 2 in thick is used to maintain the necessary level of thermal insulation for the building, which is heated by five

Fig. 1.—High-voltage laboratory as seen from control room, showing 800 kV, 2MVA, 50 c/s testing set (background, left), and 3,200,000 V impulse generator (right)



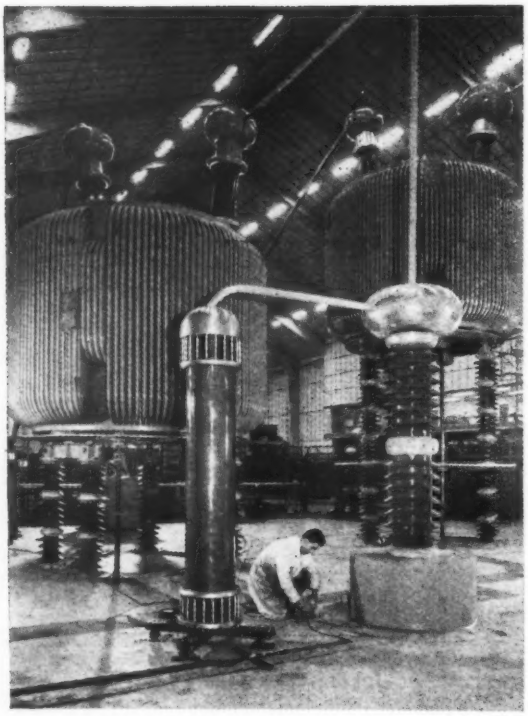


Fig. 2.—Nos. 1 and 2 transformer units of 800 kV, 50 c/s a.c. testing set. In the foreground are the capacitor stack for control and voltage measurements (right), and standard condenser for power factor measurement (left)

heat exchangers drawing in fresh filtered air from outside and maintaining a slight pressure inside to reduce the ingress of dust.

For the flooring use was made of structural concrete overlaid with a 4 in-thick metal aggregate surface finish to provide the necessary hard-wearing qualities and dustfree conditions essential in a laboratory of this kind. It will carry a point load of 6 tons anywhere over the surface of the laboratory, and certain sections are strengthened to carry the added load of the test equipment. An area at one end of the building is arranged to carry a mobile load of 60 tons spread over four points. For convenience, the reinforcing steel over the whole floor is electrically welded together to provide a ground plane which is used as an electrical measurement reference, and it is tied to nine earthing points driven into the ground to a depth of approximately 30 ft. A separate earthing system is used for earthing all the electrical supplies and the frames of the supply equipment. A comprehensive system of cable trenches covered with chequer plates extends over the floor of the laboratory and on this is superimposed rectangular metal trunking, set flush with the floor surface, for carrying instrumentation cables.

To allow for the observation of corona under conditions of darkness, there are no external windows. Instead, the building is illuminated by twin 80 W fluorescent lighting units, arranged in four rows down its length and providing an illumination of 10 to 12, lumens.

On three sides of the laboratory is a 10 ft perimeter road, the fourth side being occupied by a number of cable entries which allow cables to be run out and buried in an adjacent field, to simulate working conditions.

TEST ENCLOSURES

Great flexibility in the disposition of test enclosures was an important requirement in the design of the laboratory, so that each major item of test equipment could supply at least two test enclosures. In the final layout at least seven tests can be carried out simultaneolusly with the equipment provided. The test enclosures, having dimensions in multiples of 10 ft, can quickly be built, using standard fencing sections and posts placed in sockets set in the floor on a 10 ft grid. Full safety interlock facilities and danger lights are included in each fencing section.

IMPULSE TESTING EQUIPMENT

The 3.2 MV impulse generator (Fig. 1) is of two-column construction, having sixteen stages of 0.28 microfarad per stage rated at a voltage of 200 kV, giving a total stored energy of 89.6 kW-seconds from a generator capacity of 0.0175 microfarad. The generator is provided with automatic tripping, ultra-violet-ray gap stabilisation, remote polarity changeover switchgear and a capacitance potential divider. Provision has been made to double the capacitance and, hence, the stored energy of the generator, if required, at a later date. The generator is charged through a moving-coil voltage regulator and oil-immersed metal rectifier set.

A 1280 kV impulse generator made by B.I.C.C. is also being provided and will consist of eight stages, 0.32 microfarad per stage, rated at a charging voltage of 160 kV, and will deliver a total stored energy of 32.8 kW-seconds from a generator capacity of 0.04 microfarad. At present only four stages are completed. The generator is provided with remote polarity changeover switchgear and a resistive potential divider.

Oscillograph recordings from both generators are taken on transient recorders, built to a B. I. C. C. specification and provided with means of automatic programmed control.

A. C. TESTING TRANSFORMERS

The 800 kV a.c. test equipment consists of two 400kV transformers, capable of cascade or parallel operation and continuously rated at 2MVA either 400 kV or 800 kV, with overload factor of 1.75 for periods of up to one half-hour. They operate with live tanks, which stand on insulating supports, the mid-point of each 400 kV winding being connected to its own tank. Three-point support of the transformer tank is provided by arranging the six insulating co-

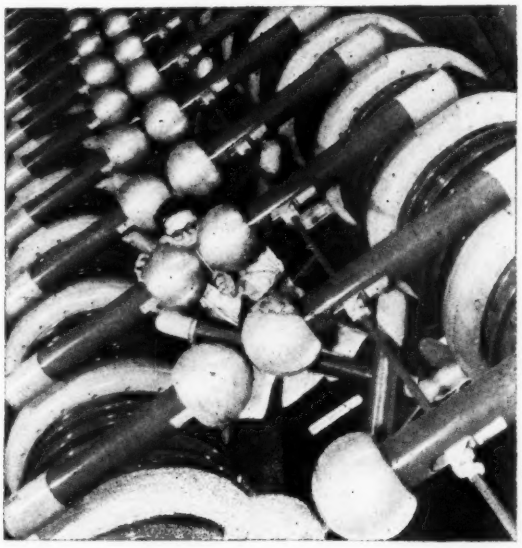
lumns in three pairs with a steel beam across the top of each pair and a ball to take the thrust, at the mid point of each beam, as can be seen from Fig. 2.

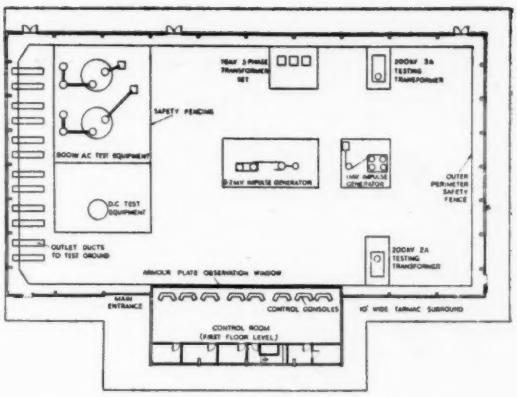
The transformers operate in a state of controlled series resonance (with tuning reactors in series with the capacitance of the cable) giving exceptionally wide stable test parameters coupled with good waveform and falling current at breakdown. The tuning reactors are situated in the main transformer tanks and are driven through an insulated shaft which is coupled to a driving and remote indication unit in a small pit under the transformers. The excitation source for the resonant circuit is in the form of two 42 kV feed transformers, continuously rated at 100 kVA each.

The tuning of the transformers and regulation of the output voltage are so electrically coupled that the two units are kept in step when connected either in series or in parallel. Provision is made to maintain the output voltage of the sets constant and to keep the transformers and load capacitance in resonance by electonic means. Electronic circuits operating from a voltage source derived from capacitance dividers, rather than from the usual current source, are provided for fault detection. This method is used because the current in the transformer winding falls, as opposed to the usual rising characteristic, when the sample under test breaks down. The series resonance circuit maintains the supply power factor near to unity with a consequent reduction in the load on the supply.

The layout of the two transformers in relation to the building is such that a third transformer can be added at a later date, if required, to extend the testing voltage to 1200 kV at 3 MVA continuous rating. In association with each transformer there is an oil header tank to take oil expansion from the transformer due to heating under test conditions.

Gap setting on 3,200,000 volt impulse generator





The Lay-out of the Laboratory and the Control Room

Also installed in the laboratory are two 200 kV, 400 kVA transformer test sets, which were formerly used at the Prescot laboratory. These transformers are fed from regulators with reactor backing and operate in the parallel mode of resonance. Their control and measurement equipment has been modified and brought up to modern standards.

Another test set which will consist of three 76 kV, 50 kVA transformers connected in a star bank is installed; it will give a 132 kV, 150 kVA three-phase supply. The instrumentation and control of this set follows conventional practice.

VOLTAGE MEASUREMENT BY SPHERE GAP

Very-high-voltage measurements can be made using a 2m sphere gap, which is provided with remote control and indication from the control room. The gap is arranged as a mobile base unit with fixed roof support for the top sphere. Mobile 25cm and 75cm sphere gaps (Fig. 1) are provided for measurement of voltages not requiring the use of the 2m sphere gap.

CONTROL ROOM

To give full visibility over the whole operational floor area the control room (Fig. 3) for the various items of equipment in the laboratory is at first floor level and protrudes about 5ft into the laboratory. Observation windows of armour-plate glass are provided along the full 80ft of the control room length. Eight control desks, built in the form of double consoles, cater for the control of equipment and all electrical measurements. Each a.c. test transformer is provided with its own Schering bridge and each of the impulse generator desks is equipped with a sealed-tube transient recorder. Next to the control room are wet and dry photographic rooms, offices and an instrument workshop.

[*Continued on page 39*

Transformer Insulation Levels

By G. B. HARPER, M.I.E.E.

The selection of a transformer insulation level, which is usually designated by the full-wave (1/50 microsec) impulse test voltage for which the windings are designed, depends mainly on three factors:—(*a*) The system voltage, which governs the continuous working stress on the insulation; (*b*) the form of system earthing, which controls the magnitude of over-voltage arising under system fault conditions and the type of winding insulation used; and (*c*) the degree of exposure to atmospheric (or switching) over-voltage involving consideration of the system arrangement and the forms of surge protection provided.

Choice of a suitable level therefore requires examination not only of the characteristics of the transformer, but also those of the system and thus forms part of the general problem of insulation co-ordination. This can be described as the process of correlation between the system characteristics, the insulation strength of its parts and the methods adopted for surge protection.

A pattern for the overall insulation strength of a transformer can be developed from examination of the different forms of impulse and power frequency voltage test and typical insulation characteristics. Such a pattern is illustrated in Fig. 1, which covers conditions associated with the British 132 kV and 275 kV grid systems based on test levels at present specified compared with levels one step lower in a standard table, i.e. 550 kV and 1,050 kV at present specified for the full-wave impulse voltage test against 450 kV and 900 kV.

PROTECTIVE DEVICES

Either co-ordinating rod-gaps or surge divertors are usually provided for protection of high-voltage transformers. A rod-gap, although a cheap and simple device, has the disadvantage that is flashover characteristics are inconsistent; also, the surge and power follow current is directly discharge to earth, disconnection of the transformer is involved. Comparison between typical vol/time characteristics for transformer insulation and rodgaps shows higher breakdown values for short time durations in respect of the latter with consequent reduced protection against steep-fronted waves. Surge divertors provide more uniform performance as their spark-over and discharge characteristics are controlled. As a manufactured item of plant, however, a surge divertor is more expensive and inherently less reliable than a rod-gap. Further, due to the material used in its construction, silicon carbide, a surge divertor also has a limited thermal capacity such that it is necessary to ensure operation does not occur during either normal or abnormal increase in the system voltage, and selection of an appropriate rating is consequently dependent on system earthing conditions. Providing reliable divertors with suitable characteristics for the system conditions are available, their use can permit selection of a lower transformer insulation strength than that necessary with rod-gaps. The use of divertors, however, involves increased capital expenditure and this needs to be considered relative to any saving in reduced transformer insulation and avoidance of plant outage.

Surge protection of transformers associated with the British 132 kV and 275 kV grid systems is provided by rod-gaps except for transformers directly connected to generators, where divertors are installed to avoid loss in output, and special cases, e.g. transformers connected to wood pole lines. Analysis of transformer faults for the 132 kV system over the ten-year period 1948 to 1958 indicates a total of 13 due to lightning and seven due to switching operations which, expressed as faults per 100 transformers per annum, amounts to an average of 0.25 and 0.13 respectively. Of these incidents the majority were associated with transformers over 20 years old whose insulation strength is

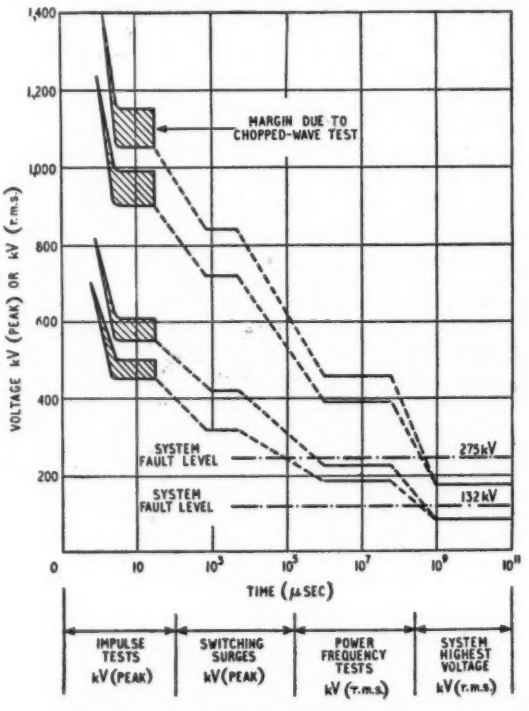


Fig. 1.—Transformer insulation characteristics

inferior compared with modern designs. In a number of cases, these faults did not result in permanent insulation damage. No similar faults have been experienced with the 275 kV system which has been in operation for a shorter period and where all transformer are of a modern impulse tested design. The low fault rate with the rod-gap settings at present used, i.e. 26 in for the 132 kV system and 48 in for the 275 kV system, cannot, however, be taken as a direct criterion of the efficiency of this form of protection and due account must be taken of the natural shielding provided by the system and associated connections. A general appraisal indicates that no advantage would be gained for British conditions by a change in the methods of surge protection employed.

Transformer test procedure at present specified covers impulse voltage tests, as type tests and power frequency voltage tests on a routine basis. Whilst the former, associated with suitable surge protection, corresponds to conditions which can arise in service, the latter bears no similar relationship giving rise to stresses somewhere between those due to switching and those resulting from system fault conditions, see Fig. 1. When consideration is being given to revision of transformer test procedure, therefore, the following may merit examination:— (*a*) Inpulse tests on a routine basis; (*b*) a test corresponding to switching over-voltages; and (*c*) a reduced power frequency test at a value showing reasonable margins over the system fault level, as a routine test.

Adoption of the above would leave the transformer designer free to develop an insulation structure directly related to system requirements without possible anomalies dictated by arbitrary test values.

The author is indebted to the chief transmission engineer of the Central Electricity Generating Board for permission to publish the information given in this paper.

(*Courtesy : Electrical Review*)

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N. G. K. JAPAN
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(Bangalore)
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Kamani Chambers,
Nicol Road,
Bombay-1.

Continued from page 37]

High-Voltage Laboratory for Power Cables

Fig. 3.—Control Room overlooking high-voltage laboratory. There are eight desks in the form of double consoles housing the control and recording circuits

Acoustic treatment is applied to the control room to reduce noise and reverberation time to a satisfactory level. Temperature and ventilation are maintained by a system of ducts set behind the ceiling, which provide warm cleaned air. The control room lighting is in the form of double and single 80W fluorescent units.

The ground floor of the control and office block accommodates a switch and regulator room, store for consumable materials, oil processing room and jointing engineers' office accommodation.

ELECTRICITY SUPPLY

The electricity supply to the laboratory is taken at 6.6 kV through oil circuit breakers to a 750 kVA, 6600/433V oil-cooled transformer. Local distribution of supplies is taken through fused isolator panels to individual electrical loads.

A ring main is provided in the laboratory to give services of 415 V, 60 A, three-phase neutral and earth and three 230 V, 13 A outlets at fifteen points around the laboratory. The main function of the 60 A service is to operate ring-type current-loading transformers and portable oil degasification plant. The lower current services are for small portable tools and similar appliances.

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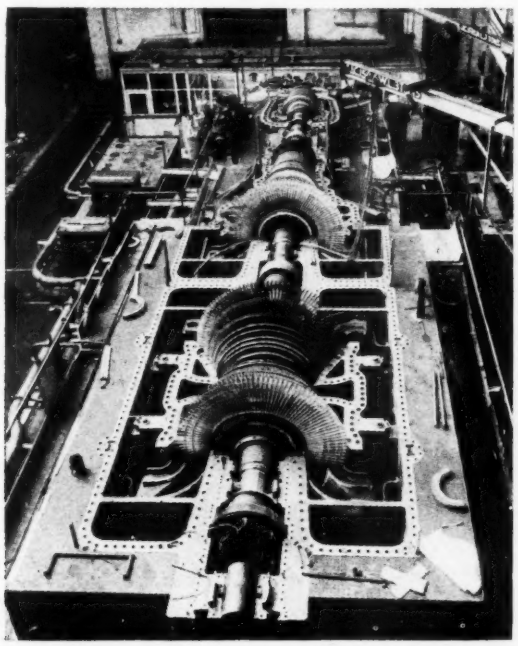
550 MW Turbo-Generator Set

It is interesting to recall the rapid increase in the size (or, more correctly, the capacity) of turbo-generator sets in this country in the past twelve years. To obtain the maximum output of plant in an era of acute shortage the immediate post-war programmes were concentrated on standard sets of 30 MW and 60 MW output. Later the Central Electricity Authority placed orders for units of 100 MW output to operate with steam conditions of 1500 lb per square inch presssure, 1050 deg. Fah. temperature and others of the same rating but with steam conditions of 1500 lb per square inch, 975 deg. Fah., with reheating to 950 deg. Fah. These machines were followed by others of 120 MW output with steam conditions of 1500 lb per square inch, 1000 deg Fah., and reheating to 1000 deg. Fah. Such a machine is shown in Fig. 1 under construction at Heaton Works for Kincardine power station.

By 1956 Parsons had received orders for machines of 200 MW output for installation in generating stations in England and Canada. The machines for England were ordered by the C. E. A. for installation in West Thurrock generating station; they will be single-line units driving a single hydrogen and liquid-cooled generator. The machines for Canada were ordered by the Hydro Electric Power Commission of Ontario, for the extensions to the Richard L. Hearn generating station, Toronto, where Parsons had previously installed four 100 MW hydrogencooled sets between the years 1951-53. The addition of four 200 MW machines will bring the installed capacity of the station to 1,200,000 kW. These 200 MW machines are of cross-compound design with the highpressure lines of the turbines running at 3600 r.p.m. and the low-pressure lines running at 1800 r.p.m., each line being coupled to a 100 MW hydrogen-cooled generator. The i.p.-l.p. line is shown (Fig. 2) erected at Heaton Works.

Fig. 1:120 MW turbine under construction at Heaton Works for Kincardine power station. The steam conditions are 1500 lb per square inch at 100 deg. Fah. reheating to the same temperature



The turbines of the single line 200 MW units are four-cylinder machines comprising an h.p. i.p. and two double-flow l.p. cylinders, the steam conditions at the stop valve being 2350 lb per square inch pressure, 1050 deg. Fah. temperature, with reheating to 1000 deg. Fah. The steam conditions for the cross-compound turbines are 1800 lb per square inch pressure, 1000 deg. Fah. temperature, with reheating to 1000 deg. Fah.

In 1957 orders were received for two machines of 300 MW output for a new generating station at Lakeview, near Toronto, Canada. The turbines for these machines will be of cross-compound design, taking steam at 2350 lb per square inch pressure, 100 deg. Fah, temperature, with reheating to 1000 deg. Fah.

In the design of the generators for the 200 MW machines under construction for the C.E.A., the limitation in size for transportation becomes a major problem. Parsons therefore decided on water cooling of the stator windings to allow a greater output to be obtained from the generator, for the same frame size and temperature rise. Permission was given by the C.E.A. to make a prototype winding for a 600 MW hydrogencooled generator which was to be installed in Tilbury generating station. This generator was commissioned in the early part of this year. The new cooling system permits generators over 300 MW to be made within the transport limits.

Such developments have made possible, to-day, the 550 MW Parsons turbo-generator. This turbo-generator will be a cross-compound unit consisting of two lines arranged in tandem, each line comprising four turbines driving a 275 MW hydrogen and liquid-cooled generator. A photograph of a model of the complete machine is reproduced in Fig. 3. All eight turbines are double-flow machines with the high-pressure cylinder on the first line. From the exhaust of this cylinder the steam is reheated and passed to the first intermediate-pressure cylinder on the second line.

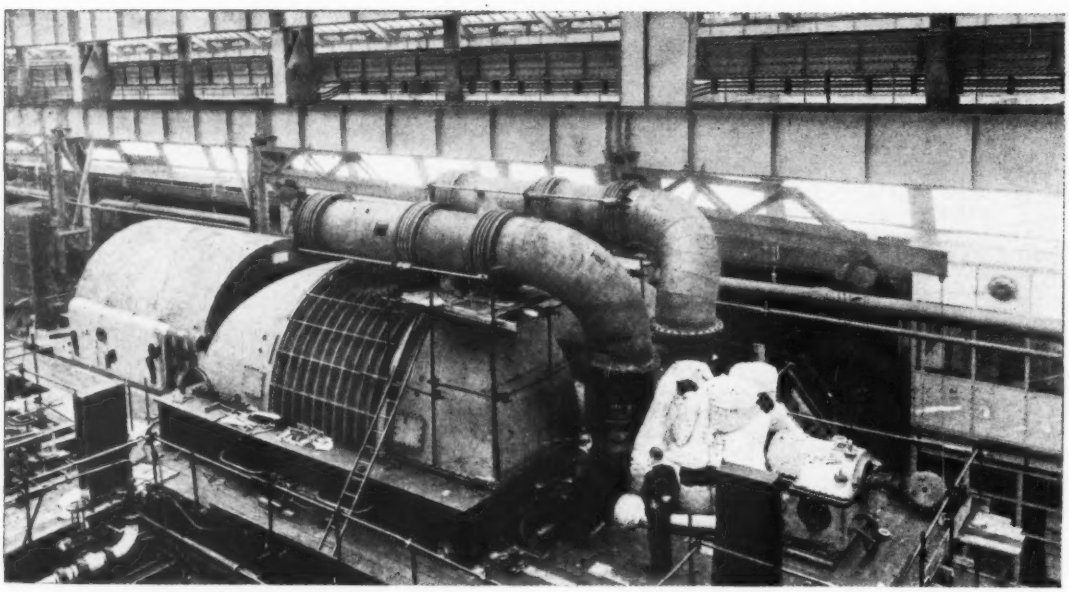
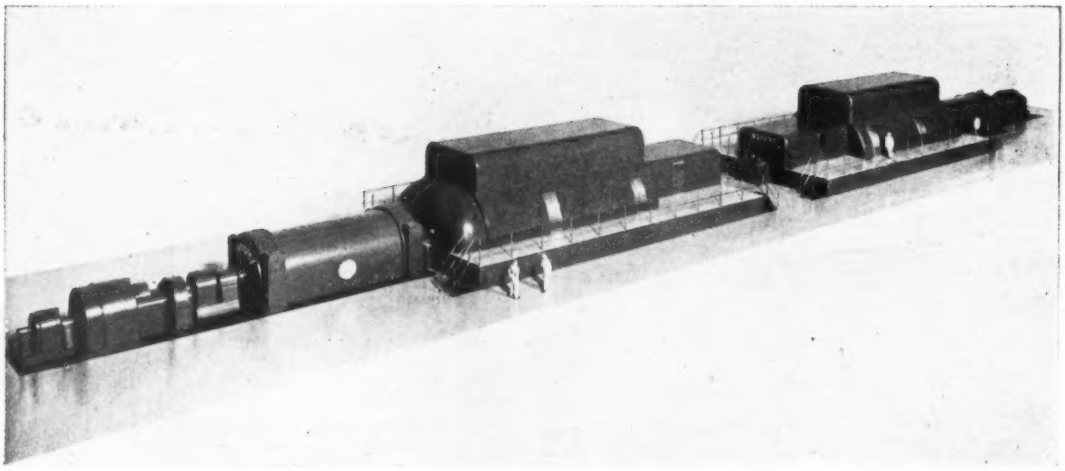


Fig. 2—I.p.-lp. of 200 MW cross-compound set erected at Heaton Works. It is one of four sets for the Richard I. Hearn power station, Toronto

On leaving this cylinder the steam divides equally between duplicate second intermediate-pressure cylinders, one on each line. Final expansion of the steam is then through two low-pressure cylinders on each line. A singlerow velocity wheel is used in the initial stage of both the high-pressure turbine and the first intermediate-pressure turbine, and reaction blading is used throughout the remaining rows. Both the high-pressure cylinder and the first intermediate-pressure cylinder are of double-shell construction.

The machine will operate with steam at an initial pressure at the stop valves of 2300 lb per square inch and a temperature of 1050 deg. Fah. Reheating is to 1050 deg. Fah. Steam is led to the turbine through two steam chests arranged one on each side of the high-pressure cylinder. Each chest is of forged construction, containing two runaway stop valves and two governor valves. Because of the large storage capacity of the reheat system, it is necessary to prevent steam flowing into the turbine when sudden loss of load occurs. Therefore, intercept and reheat emergency stop valves are incorporated iu the reheat system; release valves, which simultaneously release this steam to the atmosphere, act as an additional safeguard.

Fig. 3—Model of 550 MW cross-compound turbo-generator, consisting of two lines in tandem, for the Central Electricity Generating Board



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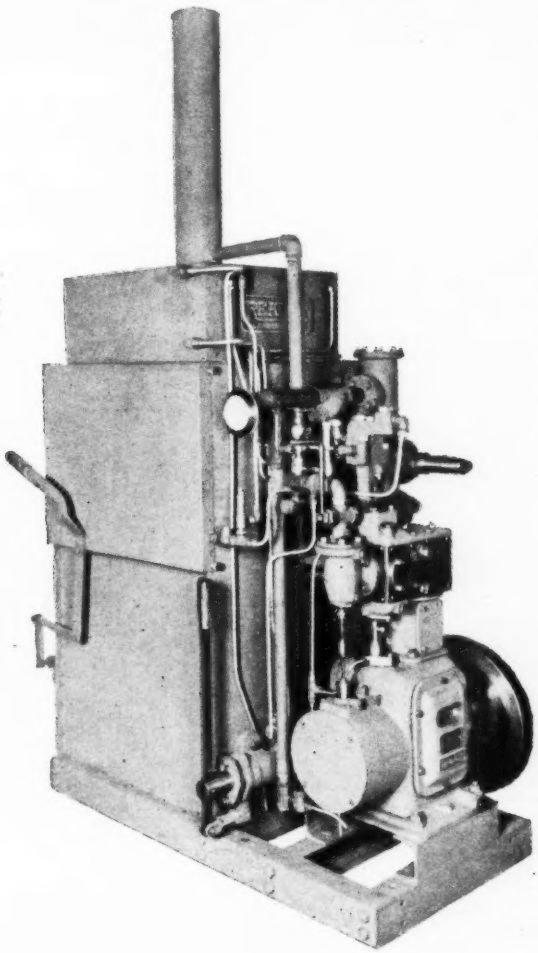
Transportable Steam-Driven Power Set

To provide a simple efficient power set for use in remote areas and undeveloped countries an interesting transportable steam power set has been developed by E. Reader and Sons, Ltd. This set comprises a 5-6 b.h.p. steam engine with a compact steam generator and weighs only 25 cwt. It can be adapted to burn a variety of fuels and is designed for safe and simple operation by completely unskilled labour.

High-speed steam engines have been made for many years by E. Reader and Sons, Ltd., Cremorne Street, Nottingham, and on the basis of its wide experience the firm decided a year or so ago to introduce a transportable steam-driven power set suitable for use in remote areas and undeveloped countries. When designing this new equipment it was decided that it would of necessity have to be of simple construction; safe for operation by unskilled labour; readily assembled and dismantled for transport; easy to maintain and service; and suitable for burning many different kinds of fuel. With these essential points in mind the firm developed and built the simple compact power set shown in the illustrations on this page.

Combined steam engine and generator, 5—6 b.h.p. power set assembled ready for operation

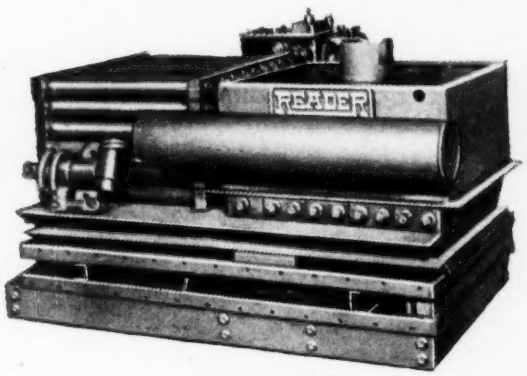


The set is assembled on a frame base member and comprises a steam generator, having a working pressure of 120-150 lb per square inch and a nominal evaporating capacity of 300 lb per hour, with a vertical steam engine developing 5-6 b.h.p. at 450 r.p.m. which is able to attain an intermittent overload of 7-8 b.h.p. The way the main component units can be dismantled and packed in a relatively small compass is shown in the second illustration. The total weight of the complete set is under 25 cwt. and the heaviest part can be carried with ease by two men.

The steam generator can be operated with complete safety by unskilled labour. It does not incorporate any orthodox fire drums or headers, and as only ten pints of water are contained in the evaporator circuit the danger of explosion is virtually eliminated. We are informed by the makers that in experiments to test the degree of safety the water supply to the generator was cut off deliberately whilst the set was under full load. After a period during which the water had been exhausted in the circuit a full flow was then re-introduced without the occurrence of an explosion or causing excessive damage to the tube elements.

The steam generator is of controlled flow monotube design, the evaporator circuit being arranged to flow

Power set dismantled and packed for transport



backwards and forwards in a zig-gag manner across and down a series of horizontal banks of tubes. Water is pumped to a feed tank above the tube element from any available source of supply. such as a river. From the tank the water is pumped directly through a preheater at the bottom of the tube element. delivery being controlled by a low-pressure regulator and a surplus water regulator. From the preheater the water passes up through a tubular de-superheater to the top of the evaporator. Steam leaves the evaporator at a temperature of about 750 deg. Fah and passes through the de-superheater directly on to the engine via a temperature control regulator.

To ensure effective heat transfer and reduce the volume of water required in the circuit to the required minimum, cored element tubes are used in the evaporator section of the steam generator. These elements of chromium molybdenum seamless steel tube have a 1.5 in diameter bore and into them are fitted core tubes of 1.25 in diameter. Through spigots welded into each end of these core tubes they are supported centrally in the element tubes from plugs screwed into connector blocks fitted between the ends of the tubes. The core tube spigots have a degree of endwise movement in the supporting plugs to compensate for longitudinal expansion. When it is required to inspect, clean, or de-scale the main tube elements the plugs are removed and the cores withdrawn to give free access without need for disturbing the connector blocks or any other parts of the main assembly.

A hand-operated pump fitted at the side of the engine is used to transfer water from the feed tank and fill the evaporator tubes for starting purposes. Immediately sufficient steam is available to run the engine the main automatic feed pump comes into operation.

The firebox at the base of the generator assembly is of steel plate with a refractory lining and it can be arranged to burn most forms of fuel varying from low grade coal, lignite or peat to wood and agricultural wastes. A large soot door is fitted at the front of the firebox to allow external cleaning of the evaporator tubes. The exhaust steam and gases from the firebox leave the set through a chimney above the water tank.

The single-cylinder double-acting steam engine used on the set is totally enclosed and of weatherproof construction. It has a bore of 4 in with a stroke of 3 in, and its piston valve mechanism is arranged for reversing the direction of rotation if required. A heavy flywheel at one end of the crankshaft incorportes a driving pulley. A totally enclosed governor mounted on the opposite end of the crankshaft actuates a sliding double-beat valve to give a close degree of speed regulation. The lower part of the crankcase provides a large oil reservoir for an effective splash lubrication system, and the consumption of oil is stated to be negligible, a dipstick being fitted for checking oil level when necessary.

One of two automatic pumps fitted above the engine draws water from the source of supply and delivers it to the feed tank. The second pump delivers the water to the steam generator. Once the engine is running it is stated to be impossible for the boiler to be deprived of water unless the suction side of the supply pump is allowed to run dry. The set is particularly designed for use in areas where water supplies have to be drawn from natural sources where fine solids are often in suspension. For this reason strainers are fitted on both suction and delivery sides of the pumps and a settling chamber is provided in the feed tank.

All control gear on the engine is mechnaically operated, and no thermostatic or diaphragm controls are used. When initial setting of the controls has been completed, it is stated, no further adjustment should be necessary, and safety covers are incorporated on all essential controls to prevent unauthorised tampering.

The set is stated to be of sufficient power to drive a 3 kW generator; a pump of some 10,000 gallons an hour capacity; or equipment such as a circular saw, threshers, grinding mills, &c. A demonstration set at the maker's works is coupled to a belt-driven generator, and with it wide range of load conditions can be simulated to show the capabilities of the equipment.

DURGAPUR STEEL PROJECT 42″ BLOOMING MILL COMMISSIONED

With the commissioning of the 42″ blooming mill Associated Electrical Industries Ltd., Heavy Plant Division, has completed the supply and installation of the electrical equipment for the first of the primary mills in Stage II. It will be recalled that Stage I of the Durgapur Steel Project was inaugurated by the President of India on 29th December 1959 when the coke oven battery and blast furnace plant were put into service and iron produced. Stage II of the project includes the steelmaking and the production of ingots for the primary mills.

From the soaking pits 7 ton ingots are carried by an ingot buggy to the entry tables where they are passed to a weighing and turning machine and then to the 42″ blooming mill. The manipulation of the ingot and its reduction to a bloom for passing to the 32″ intermediate mill involves an elaborate control scheme with regulating systems for the main and auxiliary drives incorporating amplidynes and other electrical devices. The blooms are cropped at the primary hot shear before passing to the intermediate mill. The design of this control scheme is such that the operator in the mill pulpit has complete and precise control of all the operations by the simple movement of a few controllers.

The twin drive for the 42″ bloom mill consists of two d. c. motors each of 3,000 h. p. developing a combined peak of 15,000 h. p. the normal speed range being of 40/80 r. p. m.

The main mill motors are supplied by a flywheel M. G. set consisting of four 1,200 kW and two 480 kW generators driven by a 5,000 h. p. induction motor. The flywheel has a stored energy capacity of 200,000 h. p. secons. The 1,200 kW generators supply the main drive (two generators for each motor) and the 480 kW generators supply the bloom shear motors.

Advances in Electrical Equipment

By Michael George

Everywhere in the Commonwealth the production of electricity is increasing, bringing with it demands for a broadening range of electrical equipment. This must obviously mean more opportunities for the export of British-made equipment, yet exports to Commonwealth markets in 1957 and 1958 have shown some fluctuations, as will be seen from the table at the end of the article.

British manufacturers are confident that in 1959 will see an upward trend in exports, but electrical equipment faces no less competition than other British products, and Commonwealth markets cannot be taken for granted. The industry is well represented by the British Electrical and Allied Manufacturers' Association, whose efforts to strengthen the export position include overseas committees designed to maintain direct contact with overseas markets. The first two committees began their work in Australia and India is 1915. Other Commonwealth countries in which this representation exists are South Africa, Hong Kong, Malaya, New Zealand, Pakistan and Central Africa.

Among recent major Commonwealth projects to which the British electrical industry has made vital contributions, the Kariba scheme is probably best known. Perhaps more important is Associated Electrical Industries agreement to establish a heavy electrical machinery industry in India. It is in keeping with modern thought on aid to the developing countries that this includes an elaborate training scheme for Indian engineers, both in this country and in India.

In the many new industrial plants which have gone up in the Commonwealth since the war, a new trend in the method of transmission of power to the machine has been most marked. Group drive, where one motor drives shafting to which were previously coupled many machines—a legacy of steam-and oil-engine days—has given way to a new type. In this individual motor drives are used, each machine having its own motor or motors. This results in greater flexibility, reduced electricity consumption and easier maintenance.

An even more recent development is the multi-motor machine. Here individual motors carry out different operations, either simultanerously or in sequence. Such drives are widely employed with machine tools and when combined with electronic control a high degree of automation becomes possible. Both these trends may be observed everywhere in Britian. In the very large number of new factories put up since the war in Australia, South Africa and many other Commonwealth countries, it has been possible to take full advantage of such developments from the blueprint stage.

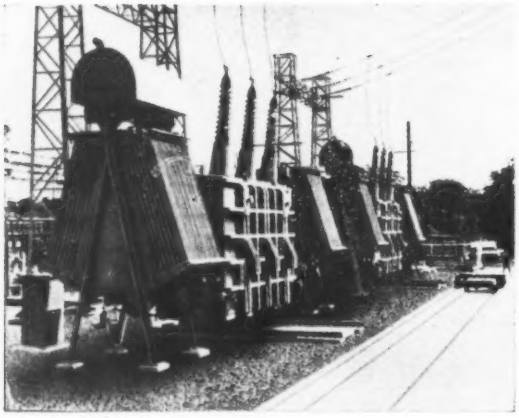
Hardly any industry has failed to benefit from the simple, easily installed electric motors which have been developed in Britain in an astonishing variety of types, sizes and ratings. They have made possible the modernisation of production lines, not only in textiles but in iron and steel, newspaper printing, mines and many other industries.

In the control and transmission of electric power on the huge scale of today, switchgear must be completely reliable. Much of the confidence placed in British switchgear, whether of the air-blast, bulk-oil or small-volume type, is based on the knowledge that its performance has been proved. This is done at one or another of the high-voltage stations owned by members of the Association of Short-Circuit Testing Authorities. Definite ratings can be assigned to circuit breakers, for example, and the testing stations have been periodically expanded in the 30-odd years they have been working in order to meet the adoption of progressively higher voltages. As a result, it is universally recognised that British switchgear is more rigorously specified and tested than any other in the world.

Improved testing has also resulted in important recent advances in the construction and performance of transformers to which British engineers have made significant contributions. An important feature is the use of cold-reduced grain-oriented steel to lower iron losses, while imporvements in tank design have given smaller oil content and weight as well as better appearance.

British transformer makers have for some years advocated the adoption of large three-phase units and one manufacturer alone has supplied 56 three-phase units in sizes larger than 60,000 kVA for voltages up to 300,000 volts. Many of these have gone to Commonwealth countries: more recently several orders for transformers for Australia and Central Africa for service at 330,000 volts have been placed with British firms. A British company, Allen West & Co. Ltd., provided all electrical starting and control gear for the world's three largest graving docks: at Southampton, Sydney and Cape Town. The same company also specialises in meeting the needs of machine-tool manufacturers for different types of motor-control equipment.

British manufacturers have carried out important lighting installations in all parts of the world. One of the most recent is the contract for Niagara Falls,



Two 30,000 kVA. transformers built by the Hackbridge & Hewittic Electric Co., Ltd., for the New South Wales Railways. Similar units are installed in many other Commonwealth territories

where a new form of floodlighting with colour changes will add a new beauty to the Falls. An innovation of particular interest in Australia, Canada and other countries where labour costs are high is the use of large scale systems of trunking. These considerably simplify lighting installation and enable systems to be more readily changed, thus reducing costs.

The success of automatic production control, no less than the progress of scientific research, is dependent on the reliability of instruments, meters and relays. British intruments by firms like English Electric, Ferranti, Marconi and many others are in use all over the Commonwealth. Any type of instrumentation, for any form of control or automation, as well as for all fields of research can be provided by British instrument makers.

In telecommunications, British engineers were the first to realise the possiblity of provideing amplifiers, called repeaters, to work on the seabed. And British cable manufactures are playing a leading part in many Commonwealth electrical undertakings. For instance, British Insulated Callenders' Cables Ltd., is the world's largest manufacturer of cables and conductors. Insulated wires and strips of every type are produced, including the special high-temeprature cables used in the Calder Hall Atomic Power Station and overhead cable equipment for railway electrification all over the world. Another firm well known for wires and cables, Henley's, has recently added to its range a number of cables insulated with the new synthetic materials, such as silicone rubber, butyl rubber. Terylene and Tersil. Tersil it is stated, will even function during and after a fire.

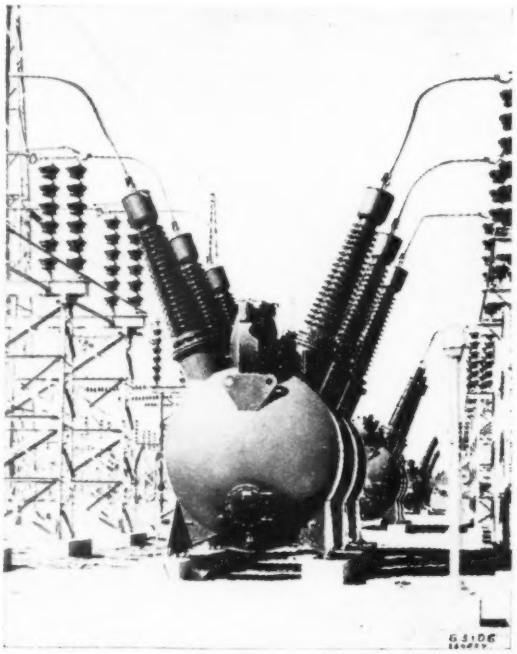
For 60 years British manufacturers have led in the development of electric trains, tramcars and trolleybuses, which have given excellent service in every continent and climate. In recent years electric railway equipment has been supplied to almost every Commonwealth country where electric railways exist, including Australia, Canada, Ceylon, Ghana, India, Malaya, New Zealand, Nigeria, Rhodesia and Souh Africa.

Among British firms supplying railway equipment, English Electric claims to be unique in designing and building complete locomotives and trains in its own works. Complete electrification schemes have been carried out in India, New Zealand and South Africa. Metropolitan-Vickers has also done some very notable work in supplying locmotives in New South Wales and trolleybuses in New Zeaand. Cromptom Parkinson is another company well known for electric transport. Some 14 955-b.h.p. diesel electric locomotives were supplied for the Commonwealth Railways of Australia, while 13 400h.p. 3 ft. 6 in. gauge mixed-traffic locomotives for Ghana Railways had electric traction equipment by this firm.

British Thomson-Houston has provided electrical equipment for many overseas railways, incuding the Bombay, Baroda and Central India Railway and the Victoria Railways. Diesel-electric equipment was also supplied to the railways of Western Australia and New South Walles.

In 1946 the printed circuit was invented in Britian. This system reduces weight and grealty simplifies production and maintenance cf the most complex elec-

Oil circuit breakers supplied by the British Thomson-Houston Co., Ltd., to the British Columbia Electric Co., Ltd. British switchgear is more rigorously specified and tested than any other



tronic devices. Instead of connecting the components of an instrument by wiring, a copper foil sheet is mounted on a plastic plate and etched to provide the necessary connections. The use of transistors makes another vital contribution, reducing power input needed by as much as 99.5 per cent. and making possible much smaller installations than would otherswise be needed.

Almost all industries in Britain and other Commonwealth countries now use some form of electronic equipment. It may be for motor-speed control for balancing the crankshafts of cars, for automatically weighing, mixing and batching foodstuffs and other materials, for detecting impurities or for controlling conveyor systems. Drilling cutting and milling tools can be made to produce machined parts of great accuracy at 20 times the speed that a main can control the machines.

Despite growing world competition Britain leads in the provision of radio and TV requirements and in such things as computors, marine radar, nucleonic instruments communications sytems, echo sounders, air navigation and sound reproducing equipment. But this specialised industry so far lacks the direction and balance in the export field that Beama has helped to give to the older electrical equipment industry. Some specialised trade association is belived by many to be essential if a properly co-ordinated export effort is to be achieved and maintained.

Britain was once the leading exporter of electrical equipment; now she is second to the U. S. A. Wnile it is true that this lead was lost during the war years, it is also true that there is now growing competition from other countries, notably Western Geremany. Although the U. K. increased its exports in 1957 by 11.5 per cent., its share in world exports has gone down very slightly since 1952.

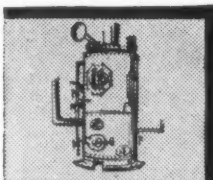
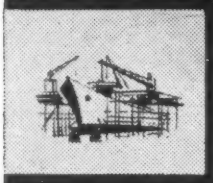
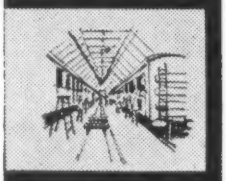
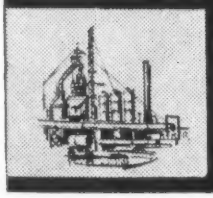
Clearly the industry cannot be satisfied with this picture and there is likely to be increased expenditure on research, already running at some £30 million annually. There will also be further concentration on the work of building up a reliale system of standards, in which very considerable progress has already been made. While the best companies are alive to the need for sending top-level personnel overseas to investigate their customers' requirement, this cannot be said to be true of all firms in the industry, and here, too, there is room for improvement.

But the British electrical industry as a whole has probably made more extensive contributions to international technical co-operation than that of any other country. It founded the World Power Conference in 1924 and has been active in the work of the Electrotechnical Commission and the International Standards Organisation. The Institution of Electrical Engineers is in the closest touch with its sister socities in the Commonwealth, through its membership of the Commonwealth Engineering Conference. With the work of *Beama*, this means that the industry's Commonwealth and international effort is an industrial force of major importance for the free world.

U. K. Exports of Selected Electrical Equipment to Commonwealth Countries

	1956	1957	1958
	(*Value in* £000s)		
Gibraltar ..	413	245	371
Malta and Gozo	858	741	668
Cyprus ..	1,630	1,534	883
Sierra Leone ..	323	430	634
Ghana ..	1,670	1,798	1,927
Nigeria ..	3,403	3,385	4,529
Union of South Africa ..	15,569	17,913	18,943
Rhodesia and Nyasaland ..	5,887	6,034	5,468
Tanganyika ..	671	867	529
Kenya ..	2,979	2,594	1,586
Uganda ..	847	954	680
Mauritius ..	281	406	456
Aden ..	551	516	647
India ..	21,215	21,955	18,709
Pakistan ..	3,714	3,063	2,523
Singapore ..	3,829	4,021	3,827
Federation of Malaya ..	3,331	3,191	3,645
Ceylon ..	2,355	1,787	1,901
British North Borneo ..	290	281	229
Sarawak ..	188	240	259
Hong Kong ..	2,768	2,999	3,676
Australia ..	21,148	20,271	19,240
New Zealand ..	10,478	11,678	13,320
Fiji ..	258	196	324
Canada ..	12,831	12,848	13,584
Jamaica ..	1,172	1,375	1,868
Barbados ..	271	236	299
Trinidad ..	1,158	1,351	1,500
British Guiana ..	463	504	808
Other Commonwealth countries	1,118	1,389	1,907
Total ..	121,769	124,802	125,929

(*Courtesy: The Commonwealth*)

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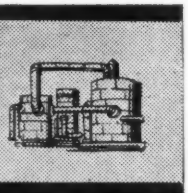
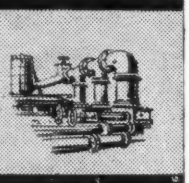
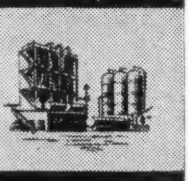
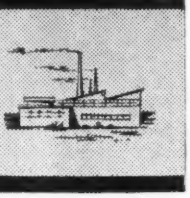

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Castle Donington Power Station

The Central Electricity Generating Board regards Castle Donington power station, Leicestershire, which was officially opened in 1958, as the biggest single step forward in generating technique up to its time. Its design and layout for a 600,000 kW capacity represented a major technical breakaway from the post-war practice of concentrating primarily on 30,000 and 60,000 kW sets of standard design which could be produced in quantity. This departure came in 1950 when load shedding was still at its height, and this decision to design the station on the basis of six 100,000 kW sets indicated considerable optimism with regard to future conditions in the generation field.

Site clearance began at the end of 1951 and the first unit was commissioned five years later. The further units were commissioned during 1957 and the fifth unit went into commission in May 1958.

ECONOMY AND PERFORMANCE MEASURES

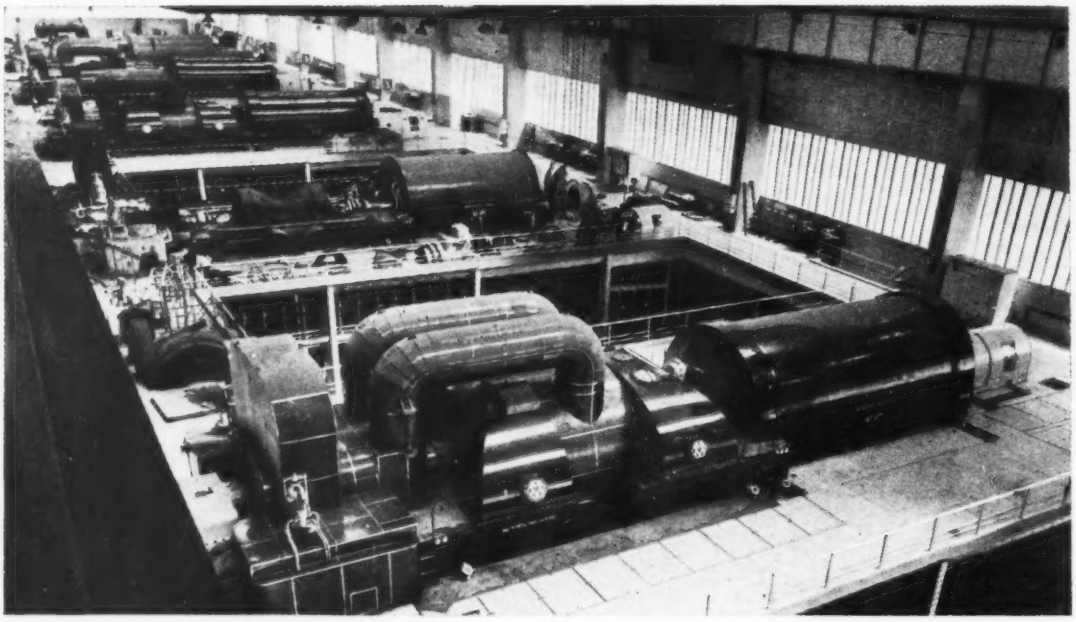
In addition to the greater capacity of the turbo-alternators and boiler units, other factors embodying new approaches towards capital economy and high performance include the omission of spare boiler capacity and the adoption of more advanced steam conditions. Each of the 100,000 kW units has steam conditions at the turbine stop valve of 1,500 lb/sq.in. and 1050°F. Each turboalternator is associated with a single boiler with a rating of 380,000 lb of steam/hr, the boilers, it is believed, being the largest in Europe.

Other "new" factors include the use of less expensive and lightweight cladding instead of heavy brickwork, and design of the cooling water system to enable maximum use of the river, supplemented with cooling towers when the cooling capacity of the river falls below the necessary level.

Perhaps the most interesting departure, from the progress point of view was the decision to design the station as an entity instead of the customary series of developments. The inclusion of six identical units with similar layouts and associated plants facilitated this principle from design, through construction to operation.

The 190 acre site is located on the south bank of the River Trent, seven miles west of Derby. The station takes its name from the adjacent village of Castle

A general view of the station, showing the boiler house "surmounting" the turbine room and the electrical annexe to the right



Inside the turbine hall, with No. 1 turbo-alternator set in the foreground

Donington, and British Railways line between Weston-upon-Trent and Sawley traverses the site.

FOUNDATION AND BUILDINGS

The subsoil comprised a layer of water bearing gravel overlying a deep bed of hard marl, and the main structures have been founded on this latter stratum. A continuous central raft 17′ thick, containing 24,000 cu.yd of concrete and founded directly on the marl, carries the heavy loading from the coal bunkers and the adjacent turbine room columns. Three 9 ft 6 in. diameter circular voids are formed in this raft, two of which serve as the flow aqueducts for cooling water to the condensers. The six turbo-alternator block foundations, containing a further 17,000 cu.yd of concrete are constructed in the same way, the return water aqueduct passing through them. The remaining portions of the building are carried on separate foundations of 19 in. diameter cast *in situ* bored piles driven into the marl and capped with reinforced concrete.

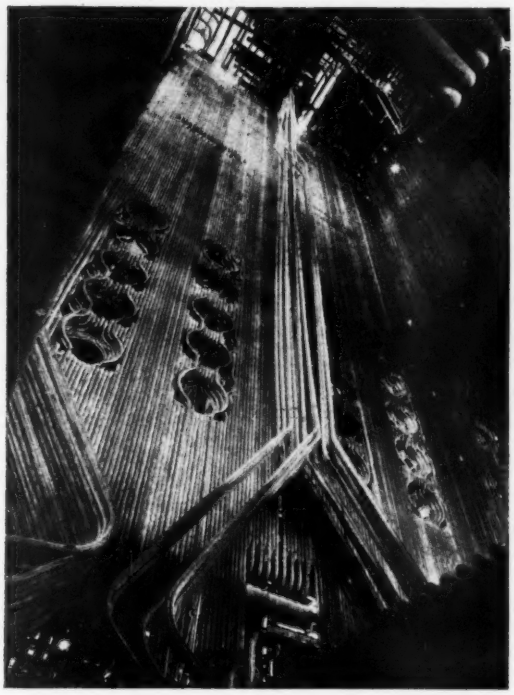
Some 900 piles were used in these foundations and a further 420 in the chimney foundations. About half the total quantity of concrete in the main raft and turbo-block foundations is colliodal concrete.

The main building consisting of the turbine room, boiler house and auxiliary plant bays, 560 ft long and 280 ft wide and the height of the boiler house is 150 ft. The size of the building which has been kept to a minimum, is 28 cu. ft per kilowatt installed. The walls of the main building are of reinforced concrete from ground or basement level up to a height of 5 ft above the operating floor level at +30 ft. At both ends of the building these walls are faced with precast concrete panels treated to expose the red granite aggregate.

The boiler house walls above the operating floor level consist of asbestos cement sheeting, of a section developed specially for this station, and adjustable metal louvres. The turbine room walls are of similar asbestos cement sheeting backed with perforated thermal/acoustic lining, surmounting a continuous horizontal band of patent glazing 11 ft high. As mentioned, these building materials were selected to avoid as far as possible the use of bricks and other materials required for house building (which were in very short supply at the time) and to achieve maximmum economy in cost. The choice of materials had been advocated by the Consulting Civil Engineers. Freeman, Fox and Partners, in conjunction with their associated architects, and the choice was supported by the Board's Consulting-Architect.

The two 425ft high circular reinforced concrete chimneys are supported on concrete rafts each with 209 bored concrete piles, and in view of their height, special aaerodynamic research was carried out at Queen Mary's College, London. It was found that unless the chimney had a circular exterior surface there would be a danger of resonant oscillation at wind speeds in excess of 60 mile/hr. The chimneys are lined with acid and heat resisting bricks, the internal diameter at the top of the chimney being 23 ft.

To implement the supply of cooling water from the river during the summer months four cooling towers are installed, constructed entirely of reinforced concrete. The towers are 300 ft high and 210 ft diameter at the base.



A dramatic view of the inside of one of the boilers (believed to be the largest in Europe) during erection

The station control room station administrative offices and workshop and stores building are in two separate blocks positioned adjacent to the main building to suit their functions. Particular attention has been paid to the layout of the first aid centre, canteen and kitchen. Locker rooms and amenities for emplyees are all located in separate blocks adjacent to the places of work.

STRUCTURAL STEELWORK

The whole of the main building is steel-framed, the total weight of steel, including the bunkers, being 9,200 tons.

All the columns and most of the girders are of welded construction, with riveted or bolted site joints. The boilers being of the top suspended type, deflections at the support points had to be kept as small as possible; mild steel was therefore used throughout.

The main boiler-support girders of 56 ft span, 12ft deep and weighing 32 tons, impose loads of about 1,000 tons on each of their knife-edge bearings 140ft above ground level. All the main columns are of simple rectangular box section; the largest, carrying 1,400 tons, measure 5 ft $\times$ 3 ft and are fabricated from plate up to $1\frac{5}{8}$ in. thick.

The bunkers are designed on the stressed-skin principle and are believed to be the lightest in weight of steel yet built in relation to the weight of coal carried.

LIGHTWEIGHT STEEL DECK ROOF

The roof throughout is of lightweight steel decking with skylights. In contrast with the heavy boiler beams already mentioned the plate griders, at 40 ft. centres, carrying the 108 ft span turbine house roof, are only 4 ft 6 in. deep and six tons in weight. These griders were delivered to the site in the halves and the centre connections were site-welded.

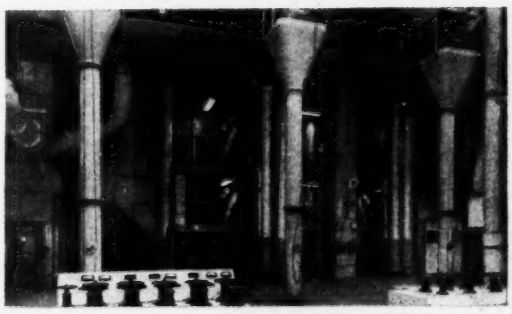
The building, being clad above turbine level with asbestos cement sheeting, lacks support from walls in resisting wind forces and diagonal bracing within the structure would have interfered with plant and access. Stability of the whole boiler house was therefore achieved by a longitudinal and transverse portal-frame construction combined with horizontal bracing in the planes of the floors.

PLANT LAYOUT

The unit system on which the station is designed implies a lack of interconnections between each of the six-turbo-alternator boiler units. In the turbine room the machines are arranged transversely, the auxiliaries associated with each machine being arranged on each side of the turbo-alternator foundation block. Outside the turbine house on the south side are the transformer bays accommodating the main generator transformers and various unit, station and auxiliary transformers. Between the south side of the turbine room and the transformer bays, the auxiliary switchgear and battery bay stretches the full length of the station with the cable tunnel beneath. The boiler house is to the north of the turbine room and between the two is the bunker bay accommodating the plant control rooms, dearators and tanks at intermediate levels.

Between the boiler house and the chimneys are the electrostatic precipitators. The ash and dust handling plant is located between the two chimneys at the rear of the boiler house. The workshop and stores building, administrative block, canteen and first aid centres are to the west of the main building and the cooling water pump house between these ancillary blocks and cooling towers, which lie adjacent

On the operating floor of the boiler house, with No. 1 boiler in the centre



to the river. The control room is located to the south of the main building between the transformer bays and the 132 kV sub-station. Immediately to the south of the main building lie the railway sidings bounded by the main line running from east to west. The coal store is to the east of the main building and adjacent to the railways sidings.

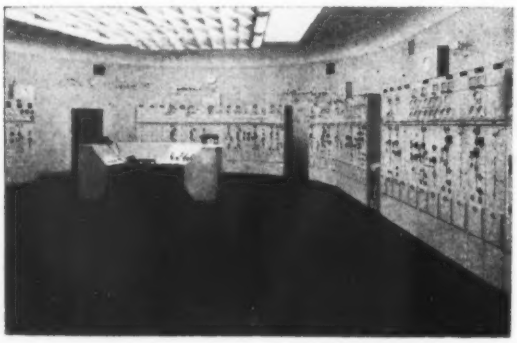
All high speed heavy auxiliaries are mounted at the basement level adjacent to the units which they serve, i.e. the boiler feed pumps and extraction pumps are at basement level in the turbine house and pulverizing mills, primary air and forced draught fans in the basement of the boiler house. The induced draught fans are at ground level between the precipitators and the chimneys.

COAL HANDLING PLANT

Coal is transported to the site in rail wagons, groups of which are shunted to the side tipping wagon tipplers where they are emptied and moved off by electric capstans. The empty wagons are then marshalled into trains for returning to the collieries. The coal handling plant comprises four side tipping wagon tipplers, which are fitted with automatic doors and dust exhausters to prevent dust nuisance, and discharge into hoppers and on to belt conveyors. The belt conveyors then transport the coal either to the boiler bunkers or to the coal stock. Electro magnetic vibrating feeders and coarse coal crushing equipment are incorporated in the belt train. The plant is designed to handle standard railway wagons with capacities up to 24½ tons and the tipplers will deliver coal at the rate of 180 ton/hr, when handing waogns with a capacity of 12½ tons.

Coal can be delivered to the bunkers at the rate of 960 ton/hr either from the tipplers or reclaiming from the coal store. The coal is stocked out or reclaimed from the coal store by belt conveyers, each approximately 2,000ft long, running the full length of the store, working in conjunction with a travelling transporter and hopper for reclaiming purposes and an automatic belt tripper for stocking-out purposes. Bulldozers are used to facilitate the movement of coal across the storage area. Road borne coal can also be received by the coal handling plant.

The main control room is of horseshoe shape, to give operators the most convenient visual control



The coal store has an area of approximately 40 acres and can store 536,000 tons of coal at a depth of 15 ft.

BOILERS AND STEAMRAISING PLANT

Each of the six steam raising units has a an evaporation rate of 830,000 lb/hr when utilizing feed water with a temperature of 400°F. at the economizer inlet. The steam conditions at the superheater outlet are 1,600 lb/sq. in. gauge and 1,060°F. Each unit comprises radiant boiler, primary and secondary superheaters, economizer, air heaters and forced and induced draught fans together with fuel pulverizing and plant oil burning lighting up equipment.

The boiler and furnace section constitute twin furnace chambers of the fully radiant type without convection surface. The twin furnance is formed by an additional central water wall and reduces the ratio of furnace volume to cooling surface, thereby allowing a lower temperature gradient between the centre of the furnance and the water walls. The single boiler drum, water walls, boiler and superheaters are suspended from the main building steelwork.

The primary superheater is in three banks and is of the horizontal self draining type. The secondary superheater is of the pendant type. Interposed between the two sections of the superheater is a pair of spray type attemperators which control the final steam temperature to within plus or minus 15°F. of the desired figure. Coarse control of the steam temperature is obtained by selection of the fuel burners which are arranged in tiers.

PULVERIZING EQUIPMENT

Five pressure type ball pulverizing mills, each with its associated primary air fan, are provided for each boiler. Four of the mills can maintain the maximum boiler load with normal fuel supplies. A primary air heater is installed to boost the primary air temperature when very wet coal is received. Twenty pulverized fuel burners are arranged in the front water wall of each boiler. Each boiler is fitted with twelve automatic type low tension spark ignition heavy oil burners. The oil burners are capable of carrying 10 per cent. of the maximum boiler load. Two air pre-heaters of the rotary regenerative type are provided for each boiler. The economizers are of the plain tube continuous loop type.

Each boiler has two forced draught fans driven by constant speed motors and two induced draught fans driven by two--speed motors. Before admitting the flue gases to atmopshere, via the chimneys, the dust is extracted and collected in twin electrostatic-type dust precipitators.

ASH HANDLING PLANT

Each boiler has one twin type water filled ash hopper into which the ash is discharged from the ash hoppers via high velocity sluices to ash sumps from which it is removed by grabbing crane to a drainage apron.

Surplus water with fine ash is drained off to the dust sumps and the drained coarse ash is grabbed into lorries for removal. The boilers have 12 precipitator dust hoppers each from which the dust is ejected by high pressure water jet. Each boiler also has six boiler and economizer dust hoppers and each of the two chimneys four dust hoppers, and from these points dust is ejected into the dust sluices by windswept valves fitted with automatic vacuum breaker valves.

The dust slurry is sluiced to the dust sump from where it is pumped to the dust disposal pits some 3 miles distant. Surplus water can be returned from the disposal pits to the reservoir serving the high pressure water pumps. Ash and dust disposal pits are available with an expected total life of 20 years, all within pumping distance of the station. The area of the first lagoon for ash and dust disposal, consisting of old gravel workings, is 58 acres and has an estimated capacity of 703,000 tons of ash and dust. It is expected to take five years to fill from the commissioning of the first unit.

Four high pressure water pumps are provided for sluicing the ash and dust to the sumps and four dust pumps are provided to pump the dust slurry to the disposal pits. Two return water pumps are installed at the disposal pits to return the water to the water pump reservoirs.

The four dust disposal pipe lines are 14 in. bore spun cast iron pipes with an initial length of approximately 9,200 ft which can be extended to 13,000 ft.

TURBO-ALTERNATORS

The 100,000 kW turbo-alternators are complete with their own individual surface condensing and feed water heating plants. The turbines are of the two cylinder impulse type with double flow low pressure cylinder. There are 16 high pressure stages and 5 low pressure stages each side, including a Baumann multi-flow exhaust stage. The stop valve conditions of the turbines are 1,500 lb sq/in. gauge and 1,050°F. The machines run at 3,000 rev/min. The overall length of the units has been kept to a minimum by the use of a two cylinder design incorporating increased mean diameters for the high pressure blading, forged construction of both high pressure and low pressure rotors and the adoption of a rigid coupling between the high pressure and low pressure shafts. Two steam chests containing the governing valves and combined stop and emergency valves, are mounted along side each turbine.

Steam for feed water heating is bled from the turbine at six points leading to six stages of the regenerative feed heating train. The final temperature of the feed water when the turbine is developing its maximum rated output is 400°F. The steam from the double flow exhaust of the low pressure cylinder passes into twin two-pass condensers with a total cooling surface area of 80,000 sq. ft and requiring 64,000 gal/min of cooling water. Each twin condenser is fitted with a quick start rotary exhauster for raising the siphon in various parts of the auxiliary cooling water system a vacuum bus main is installed which is connected to two auxiliary rotary air exhausters.

The extraction pumps discharge through the low pressure heaters to the deaerator surge tank and from there the water is drawn to the feedpump suction main. There are two 100 per cent. boiler feed pumps for each turbine/boiler unit. The boiler feed pumps are driven by 3,140 h.p. constant speed motors and each pump is capable of despatching 900,000 lb of water/hr through the high pressure heaters and economizer to the boiler. The discharge pressure of the boiler feed pumps is 1,950lb/sq.in.

Each turbine has a pair of single effect bled steam evaporators connected in parallel across the deaerator and No. 2 heater bled steam points and capable of producing boiler make-up water at a total rate of 25,000 lb/hr. The water supply to the evaporators is obtained from shallow wells sunk on the site and is first passed through a Hydrogen Ion/Sodium Zeolite water treatment plant. Two water treatment plants are installed with a total maximum capacity of 16,900 gal/hr. In addition to this water treatment plant a portable demineralization plant is available for starting purposes i.e. initial filling of the boilers. The capacity of this unit is 3,800 gal/hr. Water from the shallow wells is pumped to a million gallon reservoir located on high ground to the south of the site.

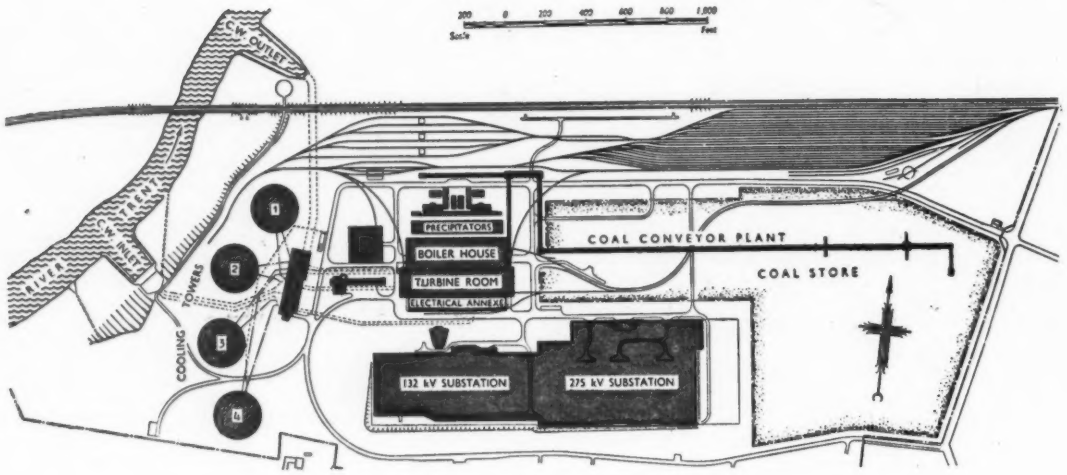
The first three alternators have a generating voltage of 13,800 and a rating of 100,000 kW at 0.8 power factor when operating at a hydrogen pressure of 0.5 lb/sq.in. above atmosphere. These three generators will be switched directly at 132 kV. The second three alternators also have a generating voltage of 13,800 and a rating of 100,000 kW at 0.9 power factor when operating at a similar hydrogen pressure. These three generators will be directly switched at 275 kV.

All of the alternators have gear driven main and pilot exciters running at 1,000 rev/min operating in conjunction with automatic voltage regulators. Each turbo alternator is fitted with supervisory equipment to provide indication and recordings of the shaft position, eccentricity, vibration, differential expansion and speed.

The hydrogen cooling sytem of the alternators consists of gas control and seal oil equipment situated within and adjacent to the main foundation blocks of the machines.

COOLING WATER SYSTEM

Cooling water for the condensers is obtained from the River Trent which has a minimum average summer flow of 8.5m. gal/hr. The total cooing water requirements of the station will ultimately be 25m. gal/hr. consequently, during periods of low river flow, the cooling towers will come into use. Also the temperature of the river must not be raised unduly and this requirement again demands the use of cooling towers. The water is drawn from the river by six river pumps, and after passing through fixed coarse screens and six



A plan of the site showing the disposition of the main buildings

travelling band fine screens it is pumped into aqueducts extending the length of the station. After passing through the condensers the water is returned to seal pits where it can either be returned to the river downstream or pumped by four tower pumps through the four cooling towers, the cooled water then being returned to the suction side of the river pumps for recirculation.

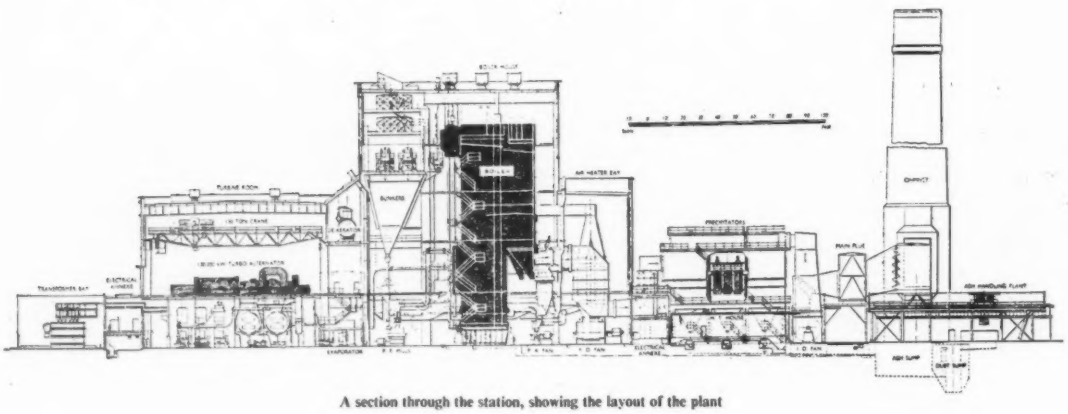
By manipulation of the appropriate penstocks in the circulating water system either direct cooling on the river or mixed cooling by the use of the towers can be employed as dictated by the river flow and temperature. The capacity of each tower is 4.5m gal/hr.

Intermittent chlorination of the cooling water is applied at the condensers to prevent slime development. This obviates the need for periodic manual cleaning of the condensers to maintain optimum vacuum conditions.

CONTROL ROOMS

Each pair of turbine boiler units is controlled from a central plant control room, located between the turbine and boiler at the common operating floor level, where all the instruments for the automatic control of the boiler, coal pulverizing plant and the turbine are located, together with remote controls for auxiliary motors, turbine supervisory equipment and alarm systems.

The main station control room, in a separate building south of the transformer bays, is a horseshoe shaped room specially designed to give the operators the most convenient visual control of the mimic diagrams and indications to the generator transformer and feeder circuits on the 132 kV and 275 kV main transmission system. The centrally positioned control desk houses the necessary controls for regulation of the load and reactive output of the six generators. The switching of the main supplies to the station auxiliary system is also carried out from the control room. Protective relay panels, metering and telecommunication equipment are housed in separate rooms in the control building.



A section through the station, showing the layout of the plant

[Continued on page 58

Grid Control Centres

A standardised system has been developed for the control centres through which the British Grid with its 260 power stations (having a total generating capacity of 22,000MW) and 350 main switching stations, are operated as a single unified system. An outline of the new scheme, together with its historical background is given here.

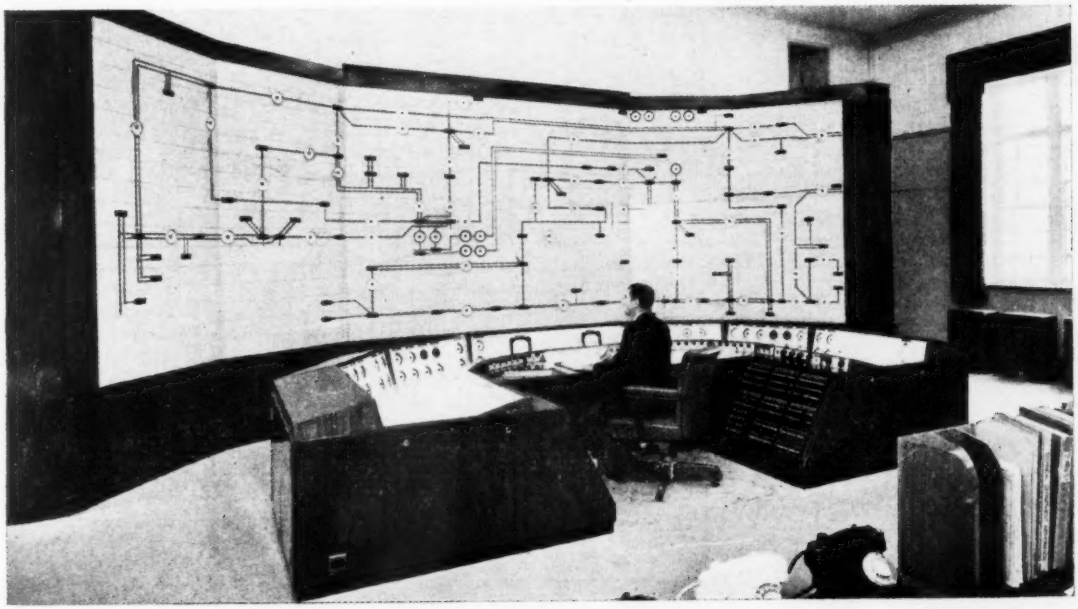
On a visit to one of the new Grid control centres last week, one can see how the operation of the Central Electricity Generating Board's electricity supply system is co-ordinated. This system, the British Grid, is the largest supply network under unified control in the world. It consists of 260 power stations with a total generating capacity of 22,000 MW and 350 Grid switching stations, the whole system being connected through the Grid and operated as a single entity so that those power stations that can generate most cheaply are used to the maximum (base load) and the stations where the genertion costs are higher are used as little as possible ('peak load).

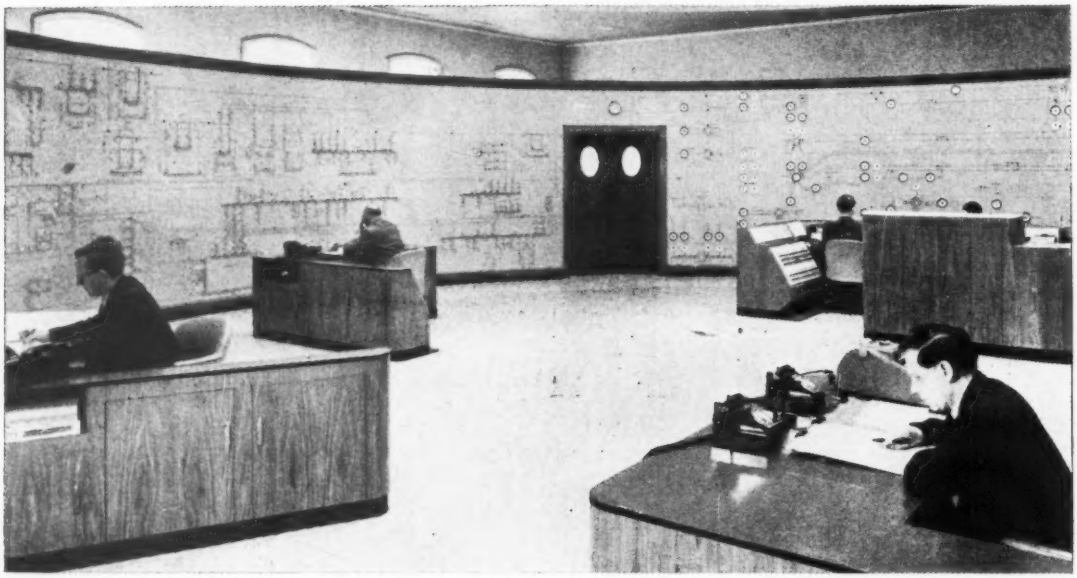
For this unified operation there are, in England and Wales, seven Grid control centres—Newcastle, Leeds, Manchester, Birmingham, Bristol and London (two) —each in direct communication with all the power stations and main switching points in their areas and a national control in London which is in direct control with the Grid control centres.

Twenty-four hours a day this sytem control organisrtiion is checking costs of generation, planning generating programmes and issuing instructions for generating plant in power stations to be started up or shut down so as to meet the constantly changing demand for electricity at the lowest possible overall cost. To do this as effectively as possible, the original Grid control centres that have existed for twenty to twenty-six years have recently been superseded by modern centres embodying up-to-date techniques and apparatus using communication and indicating equipment which is standard throughout the country.

It may be recalled that twenty-six years have elapsed since the Grid system was first put into operation by the Central Electricity Board. For control purposes the country was divided into seven districts, with combined Grid control centres (G.C.C.s) and district headquarters in London, Bristol, Birmingham, Manchester, Leeds, Newcastle and Glasgow, respectively. The Grid control areas remain substantially the same to-day, except that in 1950 the South East Control Area was subdivided into "Thames North" and "Thames South" control areas and served by the then London control centre; and with the commissioning of the 275 kV Supergrid at Carlisle, control

A View of the Grid Control Centre at Bristol





Control room of the new Thames North Grid control centre near St. Albans. One of the two switching desks is on the left facing the mimic diagram. The loading desk, right background, faces the feeder flow diagram

of the West-morland and Cumberland regions has been transferred to Newcastle. The control areas were operated as separate systems until 1938, since when they have been operated as a single national interconnected system, with the G. C. C.s under the coordination of a national control centre in London. Since 1955, the Grid in Scotland has been operated independently, but in liaison with the national control centre.

In the early 1930s, no less than five differing systems of general indicating telephone and telemetering equipment were to be seen in the various control areas. They used rented P.O. lines from the power stations in the control area to a central trunk exchange and thence to the G. C. C. in the suburbs. Signals were automatically transmitted from the stations to indicate the functional condition of circuit-breakers and the tap positions of the on-load tap-changing transformers. Communication with the G. C. C. and district headquarters was provided from special telephones in the Grid switching stations and associated power stations, which at that time were owned by power companies and town corporations. Power station control rooms also had instruction indicators which responded to any of seven instructions transmitted by the G.C.C. control engineers. In Birmingham, continuous telemetering was used, but elsewhere information was transmitted by "on request" systems. The telemeters indicated the active and reactive power transfers through the Grid transformers and on the inter-area feeders; they also indicated power station total MW generation from transmitters hand set by the power station operators. "On request" telemetering of inter-area transfers was soon displaced by continuous telemetering systems. The first Grid feeder flow diagram was commissioned in 1937 at the national control centre to display on a national scale the power transfers between the different control areas.

NEED FOR STANDARDISATION

As the Grid expanded, particularly during the war, individual installations had to be modified from time to time and the cost and engineering effort expended emphasised the need for a readily extensible and standard system for general indications, telephones and telemetering. Matters came to a hand in 1948, when the supply industry was nationalised, and it became necessary to provide communication facilities between the generating stations and the respective headquarters of the fourteen Generation Divisions of the British Electricity Authority. A year later it was decided to re-equip the fifteen-year-old Grid control networks with a standard system of general indicating, telephone and telemeering equipment, which could be extended from time to time to suit changing conditions. The installation of a "standardised system" as it came to be known, was authorised in all generating and Grid stations and most supply points to the Area Electricity Boards. Because of congestion at the existing G. C. C.s, and with recollection of wartime experiences, it was decided to build new and larger centres in more suitable districts.

THE STANDARDISED SYSTEM

The British Electricity Authority (as it was then called) and the telephone manufacturers concerned—the Automatic Telephone and Electric Company, Ltd., The General Electric Company, Ltd., and Standard Telephones and Cables, Ltd.—set up a telecom-

munications technical committee (T.T.C.) to plan and design the "standardised system." Because of the complex variety of stations and network conditions, the standardised system could not be a specific installation with universal application. On the other hand a firm standardisaion of many differnet items of equipment which could be installed in different combinations to suit the requirements of different stations was practicable. When sufficient items had been codified, and the planning parameters of the new system determined, the Authority was able to plan the new Grid control networks and issue the various contract specifications. It was decided to continue using rented Post Office lines because over the fifteen years they had proved to be satisfactory and there was, and even to-day there is, no better alternative.

In the "standardised system" the stations in a Grid control area are considered as being either major stations or minor stations. A major station is usually a generating station either with or without a Grid switching station, or is a large attended Grid switching station not associated with a generating station. Only the major stations are equipped to send signals to or receive signals from a G. C. C. A major station usually has a direct line to the G. C. C., in which case it is termed a radial station, and has also a direct line to each minor station associated with it, usually not more than three or four. A minor station is usually a small Grid switching and transforming station or a bulk supply point to an Area Board. A minor station can only send signals to or receive signals from a major station.

For economy in rented circuits the more distant major stations are connected in groups, usually of two, but up to a maximum of four stations. A group is served by a common line from the G. C. C. to the nearest or most important station in the group and from this parent station by separate lines to each of the satellite major stations in the group. Pairs of major stations served by separate lines to the G.C.C. are interconnected by tie lines to provide an alternative although indirect means of communication with the G.C.C. The more important radial stations may have second lines to the G. C. C. which are switched to take over service should the normal line fail. In everyday use reserve lines operate as inter-PAX tie lines between the G. C. C. and the stations.

A new network is being provided for the full scale transmission of general indications, telephony and telemetering to a new national control centre in London from the various G.C.C.s and will provide communication and standby telemetering facilities between the South of Scotland Electricity Board's G. C. C. at Glasgow and national control. This network will also give direct communication between the G. C. C.s. and connect with standby national control centres. The Post Office teleprinter network between national control and the G. C. C.s will be retained to reinforce the new network.

GRID CONTROL ROOMS

A different layout of equipment is adopted for each of the G. C. C. control rooms, but this departure from uniformity does not affect the "standardised system."

Mosaic switching diagrams, which have proved satisfactory for 20 years, are used.

Feeder flow diagrams were first used at national control in 1937. They incorporate telemeters in mimic power lines to indicate the magnitude and direction of active and reactive power flow in the various 275kV power lines and transformers and in the majority of the 132 kV lines. In each line a red lamp flashes when the current exceeds a present value, while at the line ends green lamps light whenever the switchgear opens the line. A typical feeder flow diagram has about 100 telemeters.

Facing the switching diagram is a control desk for each of the two switching engineers. They are equipped with keyboards for calling or answering any control telephone in the area with overriding priority over inter-office traffic. On the loading desk, which is in front of the feeder flow diagram and usually has accommodation for two engineers, chart recorders indicate area net transfer, area total generation and system frequency. Other instruments indicate rate-of-change of system frequency and daylight intensity as telemetered from the main industrial load centre of the area. The loading desk also incorporates a sixteen-way message instructor for the various out-stations and on an adjacent console there are individual power station MW generation instructors.

Each power station control desk has a control telephone and local telemeter indications similar to those telemetered to the G. C. C. of the stations' total generation in MW "sent out" and "gross" MVAr. There is also an indicator which responds to the G. C. C. loading engineer's generation instructions, and combined lamps and twist buttons for the display and acceptance of visual instructions transmitted by the G. C. C. loading engineer and a button to relight the last instruction received.

Attended transmission stations can be provided, if required with systems of visual instruction for effecting load reduction and restoration. Unless they are remotely controlled by the Area Board concerned, unattended minor stations are controlled through the standardised system over the Grid control network by the Generating Board from the associated major stations which are usually generating stations and therefore attended. As a precaution against rented line failure, however, this method of control is reinforced at the minor stations by automatic reclosure of the Grid circuit-breakers.

Design D. C. Signalling—As already mentioned the standardised system continues the established practice of using rented G. P. O. lines as the main channels of communication. Lines between stations

and G. C. C.s can be up to 150 miles long, but usually they are short enough to allow earth-return d.c. phantom signalling, which is inexpensive and does not interfere with speech or voice frequency telemeter signalling. It is unaffected by line reversal and at stations where isolation is not required the earthed positive pole 50V station batteries are used for line signalling. As this system precludes the polarising of signal train marking impulses they are marked by increasing the make period from 50 to 160 milliseconds. Unmarked pulses are transmitted at a rate of ten a second with equal make and break.

Tone Signalling and Speech.—On lines where d.c. earth return signalling cannot be used the established practice of using 300 c/s tone signalling is retained, with the speech band restricted at the lower end to 400 c/s and interrupted 480 c/s for the ringing and busy tones. This system is employed between G. C. C., parent and satellite stations to minimise impulse distortion on signal trains relayed by parent stations and because inter-station dialling between parent and satellite stations requires the d.c. channels. The speech band is also restricted to an upper limit of 2000 c/s to allow the simultaneous transmission of speech and telemetering at 2220 and 2340 c/s.

Instruction, Indication and Telephone Signalling.—From the G. C. C.s the d.c. or 300 c/s signalling channel is used to select visual messages or generation instructions at the stations and to set up telephone calls. The same channels are used from the stations to signal telephone calls and the indications of circuit-breakers, automatic isolators, overloaded feeders, direction (import or export) of telemetered power transfers, loss of telemeter channels between stations sand acknowledgement of visual message instructions. To prevent lock-out due to channel congestion during heavy traffic, the selection, indication and telephone signal trains use the common signalling channel in turn.

When an indication train is transmitted from a satellite station it is relayed to the G. C. C. by the parent station, which, together with the other satellite stations, is then prevented from sending an indication train. With an additional group selection code, selection trains from the G. C. C. are relayed by the parent station into the local equipment or to the selected satellite station. Th telephone system used in the "standardised system" is very comprehensive and incorporates many innovations and facilities to enable to meet operational requirements.

Telemetering.—When more telemeters were required in the early forties, telemeters which required individual signalling channels were superseded by multiplex systems. They served their purpose, but it was evident that telephone relays were not satisfactory for continuous multiplex operation. Accordingly, an electronic multiplex telemetering system was adopted in the "standardised system." This uses start-stop time division with 20 milliseconds marking and scans ten meters in 200 milliseconds three times a second. In the G. C. C.s the decoded impulses operate electronic telemeters to produce d.c. voltage directly proportional to the impulse rates. Indications of the direction of telemetered power flow are transmitted by the general indicating system as a point indication, which allows the full capacity of the multiplex system to be used.

Intertripping of Grid circuit-breakers between Grid stations using the control networks was introduced in 1934. The original systems were low speed (0.8 second) and became outmoded when the use of automatic 132 kV fault throwers to clear transformer and l.v. faults was approved, provided the fault level did not exceed 500 MVA. However, intertripping was still required in some situations and a number of high-speed systems have been installed during the last five years. A recent development provides for the transmission of signals, initiated by high-speed line protection, to accelerate the operation of remote distance protection equipment or to unlock inhibited directional overcurrent relays at remote transformer feeder stations.

[*Courtesy: The Engineer*]

[*Continued from page 54*

Castle Donington Power Station

TRANSFORM AND SWITCHGEAR

Alternators Nos. 1-3 are connected by 120 MVA. 13.8/145 kV transformers to the 132 kV switchgear at which voltage the machines are switched and synchronized. Alternators 4 and 5 were the first machines in the country to be connected by 106 MVA, 13.8/295 kV transformers to the 275 kV switchgear, at which voltage they are switched and synchronized, and No. 6 alternator is now connected in a similar manner. The busbars serving the 132 kV and 275 kV switchgear are inter-connected by two 120 MVA auto-transformers.

Each generator has a unit transformer solidly connected to the 13.8 kV windings to supply the essential 3.3 kV auxiliaries. In addition two station transformers and two starting transformers are provided connecting the 3.3 kV auxiliary system to the 132 kV busbars. For low voltage auxiliaries and lighting numerous transformers are supplied connecting the 3.3 kV system with the 415V switchboards. All transformers are of the outdoor type.

The 132 kV outdoor switching station will have 20 oil circuit breakers controlling three 100 MW alternators, two 275/132 kV 120 MVA auto-transformers and two banks of two 132/3.3 kV station transformers. Further switches are used for three buscouplers, two bus sections, six feeders and a reactor. There are skeleton bays for a further ten circuits when they are

[*Continued on page 66*

Electrical Power Plant for Overseas

Large generating and distributing equipments have been ordered from Britain in recent years. We give below a brief description of some of these orders placed with some of the major manufacturing companies.

A. E. I. HEAVY PLANT DIVISION

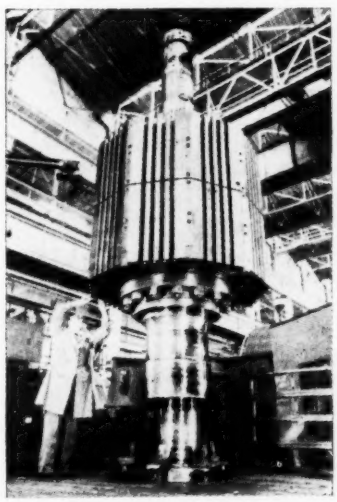
1958 saw the formation of the *A.E.I.* Heavy Plant Division and of the A.E.I. Turbine-Generator Division —the first stage in the complete integration into of hitherto separate but parallel design, manufacturing, and commercial entities within the constituent companies of Associated Electric Industries. Ltd. The A. E. I. Heavy Plant Division has its headquarters at Rugby, and its interests cover large electrical machines for hydroelectric, mine winding, rolling mill, and general heavy industrial applications; centrifugal compressors, blowers, exhausters, and boosters; gears and gearing; diesel-electric and turbo-electric marine propulsion; marine auxiliaries; and power rectifires of all types. Steam and gas turbines, turbo-type generators, turbo-type synchronous condensers, axial-flow compressors, heat-exchange plant of all types, and geared-turbine marine propulsion machinery are the responsiblity of the A. E. I. Turbine-Generator Division at Trafford Park, Manchester.

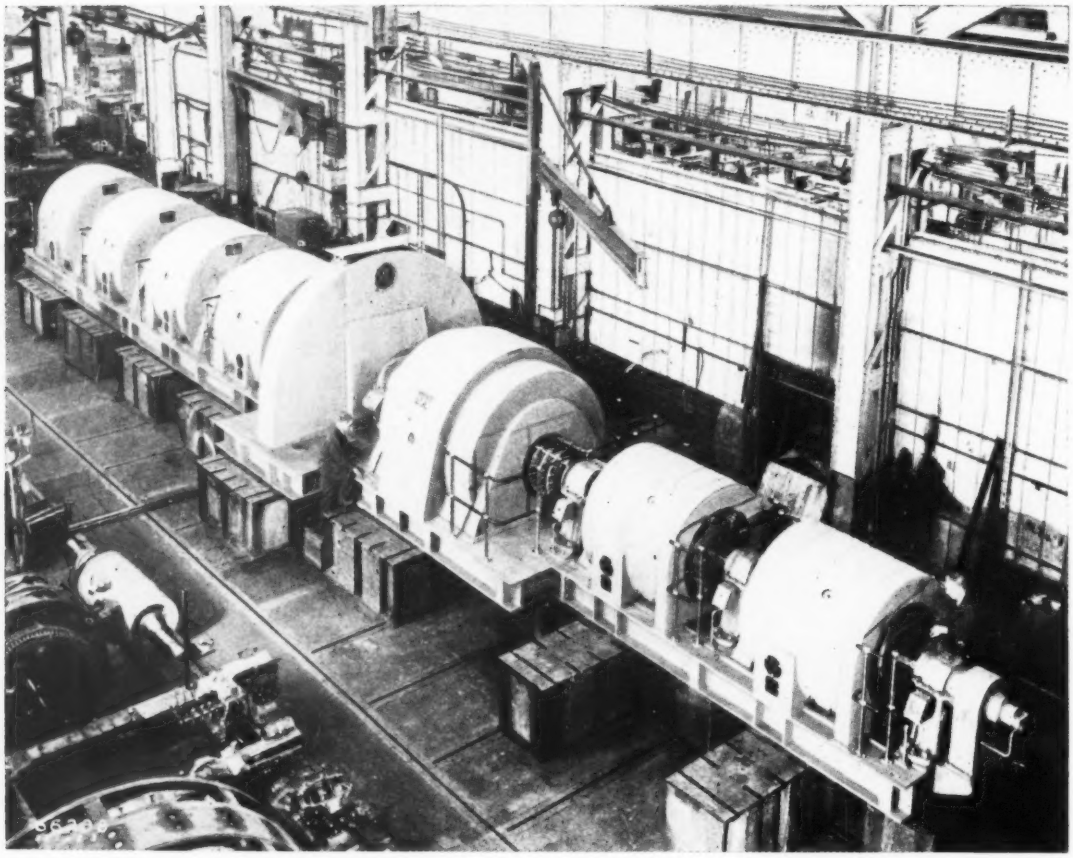
Orders for the generators for several major hydro-electric stations have been reported Recently a 32-MVA, 11-kV, 600-r.p.m. generator, one of two for Eume Power Station, Spain, was tested at Rugby. It is to be driven by a Francis-type turbine operating under a head of 850 ft (260 m). Work is proceeding on the manufacture of the second four 44,444 kVA vertical generators for Roxburgh Power Station, New Zealand, and also on the three 88,000-kVA vertical generators for Belesar Power Station in Spain. Satisfactory progress is also being maintained on four 78,900-kVA machines ordered by the Central Electricity Generating Board for the Ffestiniog pumped-storage scheme. During the course of the year the seventh 16,700-kVA waterwheel alternator was commissioned for the Uganda Electric Board at Owen Falls Power Station, and the component parts for the eighth set are on site awaiting erection.

At Trafford Park, Manchester, work is going ahead on six 100-MW, 111,111-kVA vertical waterwheel A.C. generators for the Kariba Power Station for the Federal Power Board of the Federation of Rhodesia and Nyasaland. These machines will operate at 18-kV 166.7 r.p.m., 0.9 p.f., 3-phase, 50-cycles; they will be driven by Francis-type turbines manufactured by Boving & Co., Ltd., and will be complete with automatic control gear and voltage regulators. Power obtained from these generators will in the main be used for supplying the Rhodesian Copper Belt. Shipment has already started of parts of the first two generators of the five 90-MW, 100-MVA vertical waterwheel A.C. generators on order by A.E.I. India (Pvt.) Ltd., for the Government of Punjab Electricity Branch for the Bhakra Dam Power Station. These machines will operate at 11kV, 166.7 r.p.m., 0.9. p.f., 3-phase, 50-cycles, and will be complete with protective relays, automatic voltage regulator equipments, neutral earthing and surge protection equipment. The machines will be driven by Francis-type turbines.

The third and fourth of four 16-MW, 17-778-kVA vertical waterwheel generators ordered through A.E.I., Melbourne, Australia, for the State Electricity Commission of Victoria, were shipped during 1958. These machines are designed for operation at 11.5 kV, 0.9 p.f. 600 r.p.m., 3-phase, 50-cycles. They are to be driven by Pelton-wheel turbines manufactured by Boving & Co., Ltd., and are intended for Kiewa No. 1 Power Station. The generators will be complete with main fieldcircuit-breakers, automatic voltage regulators, and associated equipment. In addition to the above, work is proceeding on two further machines for the same station, Kiewa No. 1, each of 16 MW capacity and arranged for coupling to vertical Pelton-wheel turbines also being manufactured by Boving & Co., Ltd. These machines will be completed during the latter part of this year.

Rotor for 32 MVA 11 kV waterwheel alternator being erected at Rugby





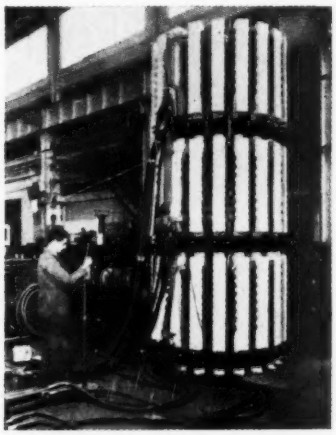
Flywheel motor-generator set for a reversing Blooming Mill in New Steel Work at Durgapur

Rugby received an order from Canada for three 450-h.p. type AKT synchronous motors for driving reciprocating compressors for Alcan for installation in British Guiana. For service in South African gold mines, orders were recived for five, 1,010-h.p., 750-r.p.m. synchronous induction motors for driving ventilation fans and for four 1,600-h.p. synchronous motors for driving pumps. For Buenos Aires Power Station, BTH-ICL Partnership, Ltd., ordered 48 large motors for driving auxiliaries. Twenty of these are for boiler-feed and booster pumps rated 3,000 h.p., 2,980 r.p.m. and 950 h.p. 1,480 r.p.m. respectively. Sixteen are for river intake and circulating water pumps rated 850 h.p., 297 r.p.m., and 490 h.p., 360 r.p.m. respectively. Ten are two-speed induction motors rated 800/450 h.p., 740/590 r.p.m. for boiler induced-draught fans and two are type AKT synchronous motors rated 1,660 h.p., 333 r.p.m. for driving compressors for sootblower air supplies.

Trafford Park reports that commissioning was carried out during September of one 50-MVA, 11-kV, 1,000-r.p.m. 3-phase 50-cycle, synchronous condenser for Torrente Sub-station to the order of Hidro-electrica Expanola S.A., Spain. This condenser was designed for erection without the use of a heavy crane, and was complete with switchgear, control gear and auto-transformers for starting. Work is proceeding on the manufacture of one 30-MVA, 15-kV, 1,000-r.p.m., 3-phase, 50-cycle, synchronous condenser, together with starting and running switchgear and automatic voltage regulator equipment required by Saltos del Sil, S. A., Madrid for their Herrera Sub-station. This condenser is to be used in conjunction with the regulating and interconnecting equipment for the 220-kV transmission line starting at Ponferrada and reaching the French frontier.

Shipment was carried out of one 30-MVA, 11-kV, 3-phase, 50-cycle, 1,000-r.p.m. synchronous condenser with associated starting equipment for San Vicente sub-station of the Hidro-electrica Espanola S.A., Spain.

From Rugby comes the news that the large "twin-drive" reversing blooming mill equipment for the new Government of India steelworks at Durgapur has been completed in the factory. This equipment comprises two 3,000-h.p., 40/80-r.p.m. reversing D.C. motors, a flywheel motorgenerator set, and all the



One of the three BTH cast-in-concrete reactor tiers for the G.E.B. Amsterdam

auxiliary drive motors and control gear. The flywheel motor-generator set and a large section of the control equipment have already been despatched, and the remainder of the equipment is nearly completed.

A number of important rolling mill equipments has been commissioned during the year. In Australia a drive for a new steel mill was installed at the latter end of 1957. This drive comprises 14 D.C. motors ranging from 250 h.p. to 1,000 h.p., supplied from two banks of mercury-arc rectifiers each rated 3,500 kW. 600 V. The rectifier transformers are provided with on-load tap-changing equipment, and the rectifiers have grid control for starting the motors and for voltage regulation. The equipment supplied includes a very large cubicle-enclosed contactor control board for the mill drive, as well as additional boards for ventilating, lubricating, and hydraulic plant and mill auxiliaries. Electronic voltage regulators and *Clearcall* equipment were also supplied.

A very important export order was received at Trafford Park for the Rhodesian Iron & Steel project at Redcliffe, near one Que, Southern Rhodesia, for main and auxiliary electrical equipment for a new 38-in (965-mm) blooming mill. The main drive comprises a 5,000-h.p. force-ventilated reversing D.C. mill motor supplied from an M. G.-set consisting of two 2,000-kW. 500-V.D.C. generator, driven by a 4,000-h.p. slipring induction motor. The auxiliary equipment comprises various constant potential and Word-Leonard auxiliary drives, the latter being supplied from an M.G.-set consisting of four 100/200-kW and two 75-kW generators, 35-kW constant-potential exciter, a synchronous motor exciter, and a 1,050-h.p. synchronous induction motor. A further order also associated with the steelworks project at Que covers two skip hoist motors and two 125-kW M.G.-sets together with charging and auxiliaries control gear for the new blast furnace.

In October 1959 a noteworthy order was received from M-V. (S.A.) Pty., Ltd., for the Union Steel Corporation, for a 16-in (406-mm) rolling mill equipment consisting of two 1,500/750-h.p. slipring main drive motors, h.t. switchgear, liquid rotor starters, and 23/30-h. p. slipring auxiliary motors and A. C. control gear.

For export U. S. A., equipment provided for a wire rolling mill comprises motors (supplied from a grid-controlled mercury-arc rectifier) for driving three stands a coiler motor; and a coiler traverse motor. Inter-stand tension control is achieved by dancing rollers coupled to magslips which feed signals to magnetic-amplifier supplied boosters in the armature circuit of the motors of stands 1 and 3. The coiler traverse motor is supplied from a magnetic amplifier to give a speed variation of 55/1 by voltage control only.

Manufacturing work continues, and some shipment of equipment has taken place, for the India Government Steelworks at Durgapur near Calcutta. This contract includes three turbine-generator sets, condensers for turbo-blowers, main and auxiliary electrical equipment for a structural mill and a wheel mill, a large number of motors, switchgear, control equipment, and transformers. Work is proceeding on the structural mill equipment which comprises a 2,500-h.p. reversing roughing stand and a 3,000-h.p. non-reversing finishing stand. The D. C. main motors will be supplied from two motor-generator sets; one motorgenerator set with flywheels and liquid slip-regulator for supplying the roughing stand motor, and a synchronous motor-generator set for supplying the intermediate and finishing stand motors. Equipment for the wheel mill consists of a single stand powered by two 500-h.p. nonreversing D. C. motors. The first D. C. control boards for the blooming mill are due to be despatched shortly, to be followed by similar boards for the intermediate mill, structural mill, billet mill and merchant mill. A number of the standard and special machines have been despatched from Manchester. These include six 360-h.p. vertical-shaft circulating water pump motors for the power plant, 65-h.p. D. C. mill-type motors for crane duties and a number of flame-proof machines for the coke-oven plant.

In the overseas field, a number of Trafford Park winders have been brought into operation. Notable amongst these is a 3,000-h.p. Ward-Leonard Ilgner cage winder with oil-servo control at the North Broken Hill No. 3 shaft in Australia, and the 4,300-h.p. A. C. geared 4-rope friction winder at Stilfontein Gold Mining Co. in South Africa. The latter employs two motors controlled by rotor contactors and grid resistances, and dynamic raking excitation is derived from a steel-tank mercury-arc rectifier. Additional equipment is soon to be commissioned to enable the winder to be operated automatically. In addition to the above, erection has started in South Africa on the first of two 6,700-h.p. geared double-drum Ward-Leonard winders for New Consolidated Gold Fields at Saaiplaas shaft. This equipment is provided with the *Lamex* control scheme and automatic operation of the winder is included.

BRUCE PEEBLES & CO., LIMITED

Trading conditions in 1958 were generally similar to those of 1957 with emphasis again on the heavier rotating plant and transformers. There were notable developments in rectifier and electronics manufacture. In all departments research continued into methods of reducing costs and raising efficiency to meet increasing competition at home and abroad. Outstanding among orders were two 18-MW generators for the Cwm Rheidol Power Station and a 12-MW generator for the Dinas Power Station, which the British Central Electricity Generating Board are building in central Wales. When completed this contract will bring the total power capacity supplied by the company to Welsh hydroelectric undertakings to well over 100,000 h.p. This connection with Wales dates from 1906 when Bruce Peebles engineered the Snowdon project, the first large hydroelectric sheme for public supply in the United Kingdom.

The oil, coal, chemical and steel industries at home and overseas have continued to order impressive numbers of electric motors of a wide range of sizes. Interesting among motors supplied in 1958 were two slow-speed 600-b.h.p. tube-cooled flameproof squirrel-cage machines, which were believed to be the largest physically of their type so far manufactured in the U. K. These motors are 8 ft 8 in (2,642 mm) high, the casing is 7 ft 8 in (2,337 mm) dia and the overall length is 9 ft 8 in (2,946 mm). Each motor contains 410 50-in (1,270 mm) cooling tubes, giving a total cooling tube length of over 1,500 ft (457m). They have been built for a chemical works and have been protected against corrosive atmospheres, this treatment being extended to the inside of the cooling tubes.

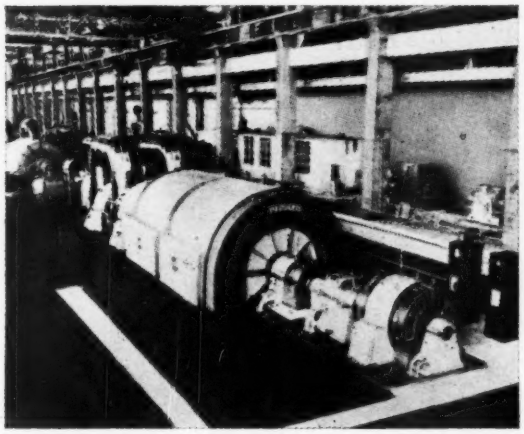
Highlight of the year in the transformer department was the despatch of the first of three 144-MVA generator transformers to the new Kincardine-on-Forth Power Station. It is the largest unit so far connected to the U. K. grid systems. Lack of a Forth road bridge capable of carrying this transformer and the consequent need to ship it across the river were factors which had to be considered in design. When stripped for transport the transformer had to weigh less than 120 tons (122 tonnes) because that was the maximum safe load of the crane at Leith Docks where it had to be placed on board. As it left the works filled with dry nitrogen the transformer weighed 118 tons (120 tonnes). Also completed during the year were the final units of eight 30-MVA transformers for Chapel Cross atomic energy establishment near Annan on the Solway Firth, one 60 MVA for Cupar substation of the South of Scotland Electricity Board and two 45 MVA's for Silsden, Yorkshire. Work has begun on the first two of three 90-MVA transformers for Magill sub-station of the Electricity Trust of South Australia. They will connect the Adelaide end of the 275-kV transmission lines from Port Augusta Power Station to the Trust's 66-kV 11-kV metropolitan systems. Weighing about 200 tons (203 tonnes) each in their operating condition these transformers will be the largest 3-phase units so far installed in Australia. The specified impulse level is 1,050 kV and the transformers will be tested on the company's 2,400-kV impulse generator.

The rectifier department handled more orders for underground battery charging equipment than in any previous year. It received towards the close of the year two orders with unusual features. The first from the U. K. Ministry of Supply is for three germanium rectifiers of 35-, 40- and 100-kW ratings respectively, which will have to operate outdoors unprotected. The rectifier elements will be immersed in oil in the lower part of the transformer tank, which will be constructed in accordance with standard practice for outdoor type transformers. A. C. supply will be controlled by a switch fuse and outgoing D.C. by a contactor. Each equipment will form a self-contained rectifier sub-station occupying considerably less floor space than a conventional unit. Mersey Dock & Haraour Board have placed an order for a 500-kW glass-bulb rectifier to operate from an 11,000 V or 6,000-V, 3-phase, 50-cycle A. C. supply and give and output variable between 450 V and 490 V 3-wire D.C. A stepless voltage regulator will provide the voltage variation and the unusual feature of the equipment is that the transformer, interphase chokes and the voltage regulator will all be naturally air-cooled and will have Class H insulation suitable for operating with a temperature rise of up to 120 deg C. This type of transformer has been specified to eliminate the fire risk, which is present in oil-filed units. The company has previosuly built power transformers of this type but this will be their first rectifier transformer of this design.

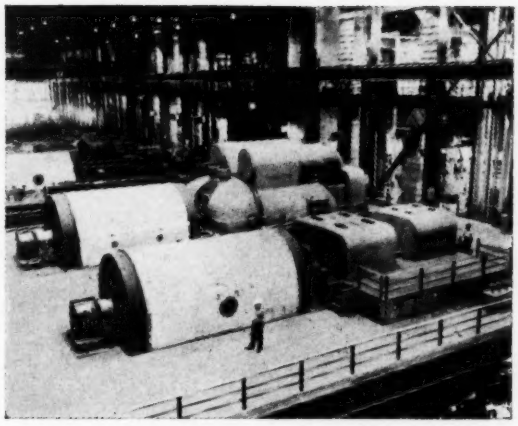
During 1958 the electronics department doubled in size and took over additional premises for both reasearch and development work. Achievements included design and production of equipment for the coal, steel, automotive, textile, electrical, ceramic and nuclear power industries plus classified work for the Government. The following examples indicate the type of output. A contactless switching system, based on the use of transductors, silicon rectifiers and resistors arranged as magnetic amplifiers having switching characteristics, has been specified by the National Coal Board for Killoch, Monktonhall, Bilston Glen and Valleyfied Collieries. Other application in the mining, steel and automatic assembly industries are being considered. A pinhole detector has been devised for the tinplate industry. Mounted on the line it can detect transmission of light through a hole having a max dimension of 0·0005 in (0.0127 mm) in a sheet of tinplate travelling at speeds up to 1,200 ft 366 m)/min. This device has attracted much attention because the only comparable equipment hitherto available came from U.S.A.

C. A. PARSONS AND CO., LTD.

The largest turbo-generator to be ordered during 1959 was the 550-MW cross-compound machine ordered by the British Central Electricity Generating Board for the Thorpe Marsh power station, Yorkshire. The machine, the largest in the world, has eight turbines all of the double-flow type, and two 275-MW hydrogen-and liquidcooled generators. Both sections of the machine run at 3,000 r.p.m. and they are arranged in line. Steam conditions at the stop valve are 2,300 lb/in² (162 kg/cm²), 1,050 deg F



Parsons 60 MW Turbo-Generator at Wangi Power Station



Parsons 200 MW Turbo-Generator at the Richard L. Hearn Plant

(566 deg C) and with reheating to the initial temperature after the high-pressure turbine. The machine's output is an increase of 250 MW over that of the largest machines previously ordered from Parsons by the Hydro-Electric Power Commission of Ontario for the Lakeview generating station. These latter machines will be the largest machines to be exported from the U.K. and the largest to be installed in Canada. The steam conditions are 2,300 lb/in² (162 kg/cm²) pressure, 1,000 deg F (538 deg C) and with reheating to 1,000 deg F (538 deg C).

In addition to these large machines, orders have been received for turbo-generators of 30,15 and 10 MW for power stations in Australia, Canada, South Africa, Jamaica and Nigeria. The first of four 200-MW turbo-generators on order for the Hydro-Electric Power Commission of Ontario for the Richard L. Hearn generating station was completed during the year and despatched to site. This machine is ready to be commissioned and is the largest set so far constructed at Heaton Works and the largest to be installed in Canada. The set is of the cross-compound type and uses steam at 1,800 lb/in² (127 kg/cm²) at 1,000 deg F (538 deg C) and with reheating after the high-pressure turbine to 1,000 deg F. (538 deg C). Parsons are also installing a 2-cyl 66-MW turbo-generator at Boundary Dam, Saskatchewan, the first of two machines for this station. Two more machines for the same output are on order for Winnipeg, Manitoba. In Australia the first of three 60-MW turbo-generators has been installed in the Wangi power station. This is the largest turbo-generator running in Australia and the first in that country to be equipped with a hydrogen-cooled generator. In the Tennyson power station, Brisbane, two further 30-MW machines have been commissioned. Other turbo-generators with outputs between 4 and 20 MW have been commissioned in India, Canada, Iraq, Jamaica and South Africa.

A turbo-blower delivering 30,000 ft³ (850 m³) of free air/min at 35 lb/in² (2.5 kg/cm²) gauge has been completed at the Indian Iron & Steel Co.'s plant at Hirapur, India. This machine is a Bessemer converter blower and is fitted with remote control to enable the set to be operated from the Bessemer converter platform.

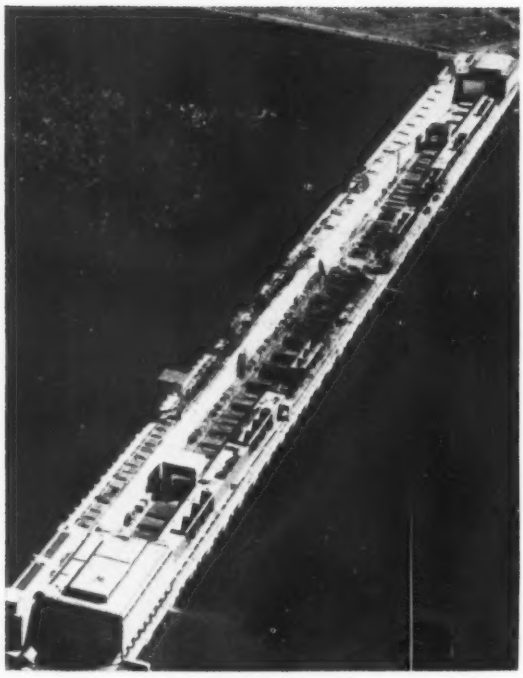
An order was received last year from The Nuclear Power Plant Co., Ltd., for three 70-MW turbo-generators to be installed in the nuclear power station to be built at Latina, Italy. The turbo-generators are of the 2-cyl type with three exhausts, and will operate with steam at 730 lb/in² (51 kg/cm²) and 700 deg F (371 deg C). Parsons now have on order or have constructed a total of 950 MW of turbogenerating plant for nuclear power stations.

The orders received this year by Parsons for transformers include many large high-voltage units for this country and for export to Australia, Brazil, Rhodesia, South Africa and Venezuela. The Snowy Mountains Hydro-Electric Authority, Australia, have ordered seven single-phase 50-MVA generator transformers with OFW cooling. These units will be connected to form two 3-phase 150-MVA banks with one transformer as a spare. Each bank will transform the output of two generators through independent delta-connected low-voltage windings and will step-up the generated voltage of 12.5 kV to the transmission voltage of 330kV. They will be installed underground and will be connected to the outgoing transmission lines by means of single-core 330-kV cables.

The Canadian Brazilian Services, Ltd., have placed orders for one 20-MVA 3-phase 138./525-kV ON/OFB transformer, and for three 5-MVA-single phase 132/25-kV units. These transformers will form a 15-MVA 3-phase bank.

THE ENGLISH ELECTRIC CO., LTD.

A highlight in the activities of the English Electric Co. in atomic power over 1958 has been the rapid progress made in the construction of the world's largest atomic power station at Hinkley Point. The Group comprising The English Electric Co., Babcock &



St. Lawrence seaway Project includes the International Power Station on Barnhart Island English Electric will contribute 16 turbines

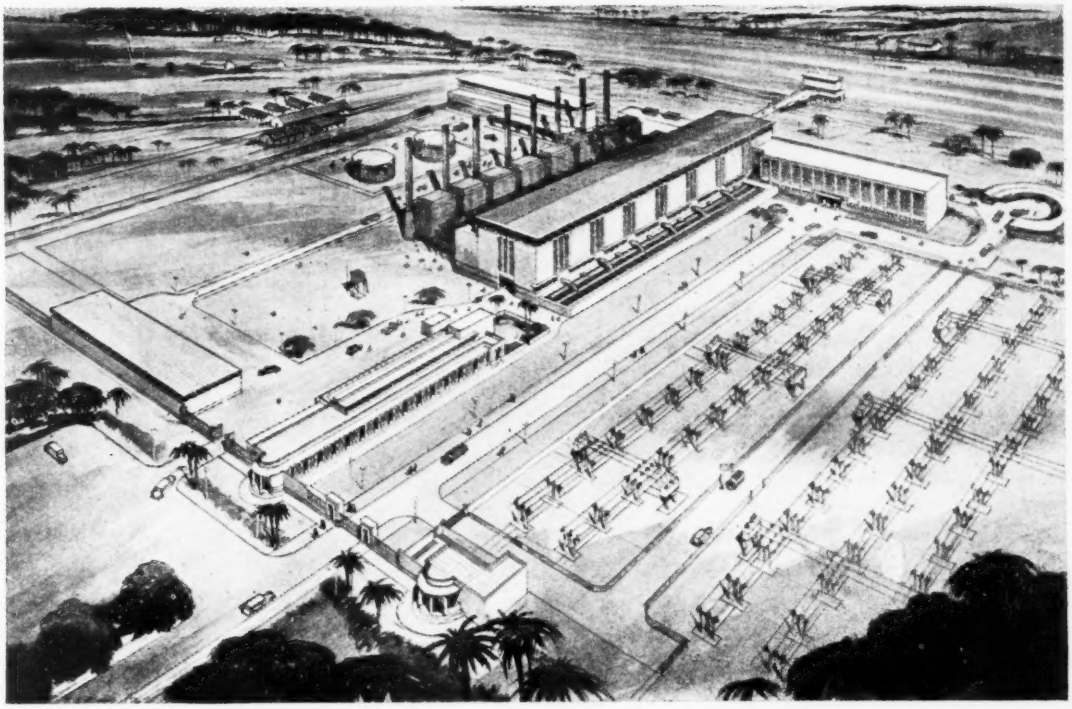
Wilcox, Ltd., and Taylor Woodrow Construction, Ltd., was awarded the £60m contract for the 500,000-kW station in September, 1957, and work began towards the end of that year. Expansion of the English Electric Atomic Power Division continues in order to meet not only the requirements of the Hinkley Point station but also the development and design of improved reactors. Facilities now include a large laboratory block for research into such aspects as atomic fuel canning materials leading to more efficient stations. Another new building which will soon be in full operation is for the machining of graphite bricks and tiles for reactors of the graphite-moderated type. Further workshop and office buildings are under construction. While close attention is being paid to the home programme of nuclear power, with designers busy on proposals for further United Kingdom stations much effort is being devoted to the export field. Technical and commercial experts of the company and its associates in this field have travelled widely to discuss requirements of various interested countries and put forward propcsals.

The year 1958 has been notable for the amount of work in progress and completed. Amongst the water turbine generating sets commissioned is the second main set at Hirakud in India rated at 37,500 kW and the second 25,000-kW set at Hume in Australia. The delivery of the four 134,500-h.p. water turbines for Snowy T.I. in Australia and of the first two 68,000-h.p. turbines for Table Rock in the U. S. A. has been completed. Other equipment delivered included the 50,000-kW hydro electric set for Warragamba in Australia, the two 4,600-kW sets for Corner Brook in Newfoundland and the two 2,500-kVA alternators for La Val in Mauritius. During the year good progress has been made on the Hirfanli hydroelectric installation in Turkey, and all three machines have been delivered to site, each unit having a capacity of 36,000 kW. The order for the plant for the Priest Rapids power station in U.S.A. was extended from eight 131,000-h.p. water turbines coupled to 95,500-kVA alternators, to 10 machines, and considerable progress is being made on this important contract.

The year has seen the completion of the Sir Adam Beck No. 2 Pumped Storage Station in Canada with its six Deriaz reversible pump turbines, and the commissioning of the first six of the 16 75,000-h.p. propeller turbines being supplied for the St. Lawrence Seaway Project. The order for Beauharnois No. 3 Station in Canada was extended from six to 10 69,500-h.p. turbines. The machines for these three contracts were designed in England to the order of English Electric Canada (a division of John Inglis Co. Ltd.), construction being undertaken by John Inglis Co. in Canada.

An order of considerable interest is the contract associated with the United Kingdom Atomic Energy Authority's new advanced gas-cooled reactor, comprising a 33-MW steam turbo-alternator set, condensing and feed-heating plants together with auxiliary apparatus. Scheduled to come into operation during 1961, the new reactor will contribute to the U.K.A.E.A. programme for realising the maximum development potential of the gas-cooled, graphite-moderated reactor. The turbine is a 2-cyl, 3,000 r.p.m. machine operating with steam at 670 lb/in² (46 kg/cm²), 850 deg F (454 deg C) and exhausting at 28.6 in (726.4 mm) Hg.

Among the export orders received, the 100-MW set for the Thunder Bay power station of the Hydro-electric Power Commission of Ontario is a 3-cyl, 3,600-r.p.m. machine, operating with steam at 1,450 lb/in² (102 kg/cm²), 1,000 deg F (538 deg C), and exhausting to a vacuum of 29.0 in (736.6 mm) Hg. Repeat orders included a third 10-MW single-cyl turbo-alternator set for Malaya. Overseas the new extension to St. George's Bay power station of the Athens Piraeus Electricity Co., comprising one 60,000-kW set and one 14,300-kW topping set, together with all boiler plant, ancillary plant, buildings, etc., has been completed. The 12th 30-MW set was commissioned at Vierfontein, South Africa, thus completing this station for the Electricity Supply Commission. Excellent progress has been made on the comprehensive contract at the North Point "B" power station, Hong Kong, and the first 30,000-kW set has been put into commission. During 1958 the order for the second extension, i.e. No. 3 set, was received from the Hong Kong Electric Co. Other sets put into operation overseas included the first 31.-5MW set for Abadan, the second 30-MW set for Umgeni, Natal, the first 30-MW set for Mercer, New Zealand, the first 10-MW set for Malacca and the 6,250-kW set for Bahrein.



An artist's impression of the New Basrah Power Station, Iraq

For The English Electric Co. 1958 has included several outstanding achievements in transformer manufacture. Two of the largest 3-phase transformers in the world—of 345 MVA capacity and more than twice the MVA of any transformer made elsewhere in the United Kingdom—were shipped to the U.S.A. The first 330-kV transformers to be built in Britain were despatched to New South Wales for distributing power from the Snowy Mountains scheme. In both cases the transformers were fully tested before leaving the works. A second 103-MVA transformer was supplied to Lecheria, Mexico, to partner the unit already in commission, and two 93.5-MVA transformers were despatched to Pakistan. So far as is known these are the largest transformers yet to be installed in those territories. Amongst the many important contracts for this class of transformers was one from Venezuela for 45 150-kVA subway transformers of the sealed type for use in pits below street level, which was won against competition from American firms. A repeat order from the City of Salisbury, Rhodesia, was for 49 transformers ranging from 25 kVA to 500 kVA.

One of the major orders in 1958 for English Electric switchgear was the contract from the Central Electricity Generating Board for the 275-kV switching station associated with the Hinkley Point nuclear power station. This station will incorporate 14 275-kV 7,500-MVA air-blast circuitbreakers, four of which are designed for high-speed autoreclosing with dead time variable down to 0.3 sec.

Amongst the many metalclad oil circuit-breakers supplied were 40 despatched to the Sudan Light & Power Co., Ltd., for the extesions connected with Wad Medani power station. Thirty-four units were ordered for the Monrovia City Council, Liberia, as part of the reorganization of the high-voltage ring-main system.

CROMPTON PARKINSON, LTD.

In 1958 the value of Crompton Parkinson's exported products reached a record total. The company was actively concerned with several large electrical development schemes, their contracts ranging from the supply and installation of plant and equipment for power system extensions to the execution of complete electrification projects. Overseas sales of 33-kV and 66-kV outdoor mounting switchgear were particularly good.

One of the largest orders received was that from the Iraq Development Board for switchgear and transformers for the Basrah Power Station. This order included three 17.5-MVA generator transformers, five 12-MVA sub-station transformers, two 4-MVA station transformers, the whole of the 33-kV switchgear for the power station and associated substations, the 11-kV an 3.3-kV oil-break and l.v. air-break switchgear and all the control room equipment. This order was valued at £400,000, C. P. being responsible for the supply, installation and commissioning of the equipment.

From Ceylon, a £250,000 order was received for three 25-MVA substations to be used in the City of Colombo distribution system. This order comprised six 12.5-MVA transformers, together with auxiliary transformers, 19.33-kV circuit breakers, control equipment and ancillary gear; one again, installation and final commissioning were e.C. P's responsibility. From South Africa, Durban Corporation ordered 12 duplicate busbar, phase-segregated, 33-kV, 1,000-MVA metalclad units, and for the first stage of a large switching station at Port Elizabeth the company supplied eight 66-kV circuit-breaker with other equipment.

Orders were received from supply authorities in India, who are regular C. P. customers, including an order for 58 6.6-kV units and another for 50 11-kV units. A further order for eight 33-kV circuit-breaers and 50 11-kV units was noteworthy in that the 11-kV units will be manufactured in the Indian works, where other orders for several 6-MVA and 4-MVA transformers are currently in hand. Further east, an order was obtained from Thailand for 21 11-kV, 500-MVA flush-fronted switch units for the Bangkok distribution system.

In the Western Hemisphere, another American order is in hand for six 9,687-kVA single-phase transformers for the Freemont Canyon Scheme. Other appreciable distribution transformer business is progressing satisfactorily in Trinidad, Bermuda, Barbados and Canada, these being mainly repeat orders for electrification extension work. Several 6-MVA transformers were ordered by an oil company in Venezuela for drilling-rig application. In Africa, further transformers and 11-kV switchgear business was effected with the Uganda Electricity Board. The annual contract for 33k-kV switchgear with Salisbury Municipality was renewed and two 10-MVA transfomers were supplied to Bulawayo for a reinforcement of the existing supply system in which C. P. equipment has been in use for many years.

Notable orders for the company's rotating plant products were received from a wide range of overseas industries, rubber, paper, and cement factories being particularly prominent users. Orders for rotating plant worth about £250,000 have been obtained for several industrial projects in India. For the Tinnevelly extension at the works of India Cements, Ltd., C. P. supplied motors. For the Star Paper Mills, Saharanpur, which are extensions to an existing mill, C. P. motors and transfomers were supplied, some of which were made in the Indian Factory and some in the U. K. One of the most interesting projects in India was the complete electrification of the new rubber factory in Madras, where C. P. supplied motors, transformers, switchgear, cabling and lighting fittings. Some of this equipment were be manufactured at the Indian factory, and some in the U. K. factories. This project is particularly interesting because the C. P. Company in Madras, Crompton Engineering Co. (Madras) Private, Ltd., carried out the complete erection and installation of the plant.

Other notable rotating plant orders came from a large flour mill in Manila and a paper mill in Roumania.

(*Courtesy: British Engineering International*)

[*Continued from page 58*

Castle Donington Power Station

required. The alternator circuitis are equipped with surge diverters.

To avoid the reserve bars of the centre section having to cross the main busbar with overhead connection having to cross the main busbar with overhead connections a short length of 132 kV, 0.6 sq. in cable, two cables per phase has been incorporated in the bars. The first and third sections of the busbars are coupled by means of a 90 MVA reactor. The rupturing capacity of the 132 kV bulk oil filled circuit breaker is 3,500 MVA. The isolators are manually operated with electrical and mechanical interlocks.

The 275 kV outdoor switching station has oil circuit breakers controlling three 100 MW generators, the two auto-transformers and three feeders connecting with other sub-stations on the nation's new Supergrid. The bulk oil circuit breakers have a rupturing capacity of 7,500 MVA. The isolators are electrically operated with electrical and mechanical interlocks.

The 132 kV cables from the generator transformers Nos. 1-3 to the substation are of the oil filled type, and those on the low voltage side of the auto transformers are similar. The generator transformers 4 and and 5 are connected to the 275 kV switchgear by twin overhead steel cored aluminium conductors spaced 12 in. apart. No. 6 is similarly connected.

AUXILIARY SUPPLIES

The auxiliary supplies have been grouped into unit boards and station boards for distribution purposes, and supplied from the various unit and station auxiliary transformers. The 3.3. kV auxiliary switchgear is of the indoor air break, single busbar, horizontal draw out truck type, with a rupturing capacity of 150 MVA. The 415V contactor switchgear is of the air insulted, air break, direct on line type with a rupturing capacity of 25 MVA. Metal clad air insulated switch fuse gear is utilized for supplies to the auxiliaries at this voltage with the incoming supplies to the switchboards controlled by air circuit breakers.

The station utilizes the services of some 1,550 auxiliary motors ranging in capacity from 3,140 h.p. for the boiler feed pumps to fractional h.p. machines used for control functions. The total installed capacity of the motors will be approximately 92,000 h.p.

The Civil Engineering Consultants were Freeman, Fox and Partners, and those for the structural design of the subsidiary buildings were R. T. James and Partners.

(*Courtesy: The Consulting Engineer*)

Technical Notes & News

Taylor Woodrow Construction Ltd.

Since 1943 *Taylor Woodrow Construction Ltd.* of London, England, a member of the Taylor Woodrow Group, one of the largest building and civil engineering group of companies in the world, has carried out civil engineering and building works for twelve power stations in the United Kingdom.

Of these, three major contracts are currently proceeding at Hinkley Point, Somerset, High Marnham, Nottinghamshire, and Northfleet, Kent—all for the Central Electricity Generating Board.

At Hinkley Point, Taylor Woodrow is in association with the English Electric Company Ltd., and Babcock and Wilcox Ltd., for the design and construction of the £60,000,000 atomic power station—the largest of its kind now under construction in the world. The majority of the civil engineering works on this contract have been completed, including the construction of the 3,500ft long sea wall and the 3,900 ton "man made" cooling water intake caisson now grounded in its final position in the Bristol Channel.

High Marnham power station, the largest thermal power station in Western Europe, will have a generating capacity of 1,000 megawatts. Taylor Woodrow's work comprises the whole of the main foundations and circulating waterworks for the station's boiler and turbine plant, cooling water pumphouse, culvert aqueducts, five prestressed turbo-alternator blocks. The second of the two 450 ft. high reinforced concrete chimneys in now nearing completion.

At Northfleet, Taylor Woodrow's work embraces riverworks, railway work, tunnelling, roadworks and office buildings, in addition to the great power house itself, and presents a distinctly varied programme within one contract. An important feature of this has been the construction of the 800 ft. long wharf wall and a jetty parallel to it with dolphins at either end which will accommodate vessels bringing in the station's coal supplies.

At Castle Donington power station, Leicestershire, officially opened in October 1958, Taylor Woodrow Construction's work included the main building superstructure, controlroom and subsidiary buildings, foundations and aquaducts, prestressed turbo-alternator blocks, railway sidings and ancillary works.

Taylor Woodrow were also the building and civil engineering contractors for the world's first atomic power station—Calder Hall "A" and Calder Hall "B"—an identical station carried out for the U. K. A. E. A.

Export of Engineering Goods South East Asia: Barter Possibilities in Thailand

A modest consignment of 47.6 meters high Communication Mast has feen exported to Thailand for the Royal Irrigation Department, Bangkok—a comparatively small event if the significance is lost sight of.

Recently the Thai Foreign Minister Dr. Thanad Khoman, who is also the Chairman of the Export Promotion Council was reported to have lost his sleep over the Indo-U. S. Food deal. India's Food Minister Hon'ble Shri S. K. Patil allayed his fears and announced that the quantity of rice included in the deal was too little for India's requirements and she would purchase rice from South East Asian Countries on barter basis.

It is a well known fact that Thailand is in need for Engineering goods. Their Yanhee Power Project alone would require 7,000 to 8,000 tons of Transmission Line Towers. And this can bring a sizeable quantity of the much-needed Rice—besides providing sound sleep to the Thai Foreign Minister.

The Communication Mast exported by Messrs. Kamani Engineering Corporation Ltd. is the first of its kind to be exported outside India. Till middle of 1950, Transmission Line Tower Industry was unknown to India. Within a decade the Industry has been fully established and has surplus capacity for export. Over 50,000 tons of Towers ranging from 22 kV to 220 kV constituting 70% of the Country's requirements have been supplied by KAMANIS to important Power Projects from Bhakra Nangal to Koyna. The Bombay firm has facilities for designing, testing, fabricating and galvanising all under the same roof, and has seperate department to look after erection, which has constructed over 1,600 kilometers of Transmission Lines.

They have so far designed as many as 200 different types of Towers for about 59 projects, 100 substation structures and about 30 Aerial and Communication Masts —the like of which has been exported to Bangkok.

Thus, this marks the begining of possibilities of export of steel structures to Thailand for their power development.

The Largest Turbo-Alternators in the World for Electrical Power Stations

Two turbo-alternators which may be regarded as being the largest 3000 r.p.m. machines ever built are shortly to be installed in France in power stations of the E. D. F.

These machines will be manufactured in France according to a design supplied by the largest Belgian electrical manufacturing concern ACEC which has just completed the entire design work.

The machines in question are turbo-alternators each having a capacity of 312,000 kVA, 24,000 Volts at a power factor of 0.8.

The field and armature windings will be constructed with hollow conductors which will be cooled by the circulation of hydrogen at an absolute pressure of 4 kg per cm^2.

These generators, which are about 12 meters in length, will weigh approximately 340 tons each.

It should be noted that by use of this technique, the Belgian manufacturer who designed the machines is able to construct 3000 r. p. m. alternators of up to 625,000 kVA capacity.

Expansion of Indigenous Manufacture of Electrical Signalling Equipment

For over 50 years Saxby & Farmer (India) Private Limited, the Indian subsidiary of the Westinghouse Brake & Singal Co. Ltd., has been manufacturing complete mechanical signaling and, for nearly 10 years, electric signalling equipment, in India. As production of electric equipment increased, an additional factory was established in 1956 and plans made to expand at a steady rate. Because, however, of the acceleration of the Indian railway development programme and the report made by Mr. John Ratter, Member of the British Transport Commission, after his recent visit to Asia as chairman of the U.K. delegation to the E.C.A.F.E. Conference, Westinghouse has arranged with Saxby & Farmer for more rapid expansion of indigoneus production of electric signalling equipment, so that within a relatively short period Saxby & Farmer will be in a position to undertake substantially the whole of the technical, manufacturing and installation work for complete installation. The expansion will comprise C.T.C. mechanised marshalling yards, power interlocking, automatic block signalling, level crossing protection and so on. The necessary specialist knowledge will be supplied to Saxby & Farmer by Westinghouse and will incorporate the latest available experience gained through that firm's world-wide connections.

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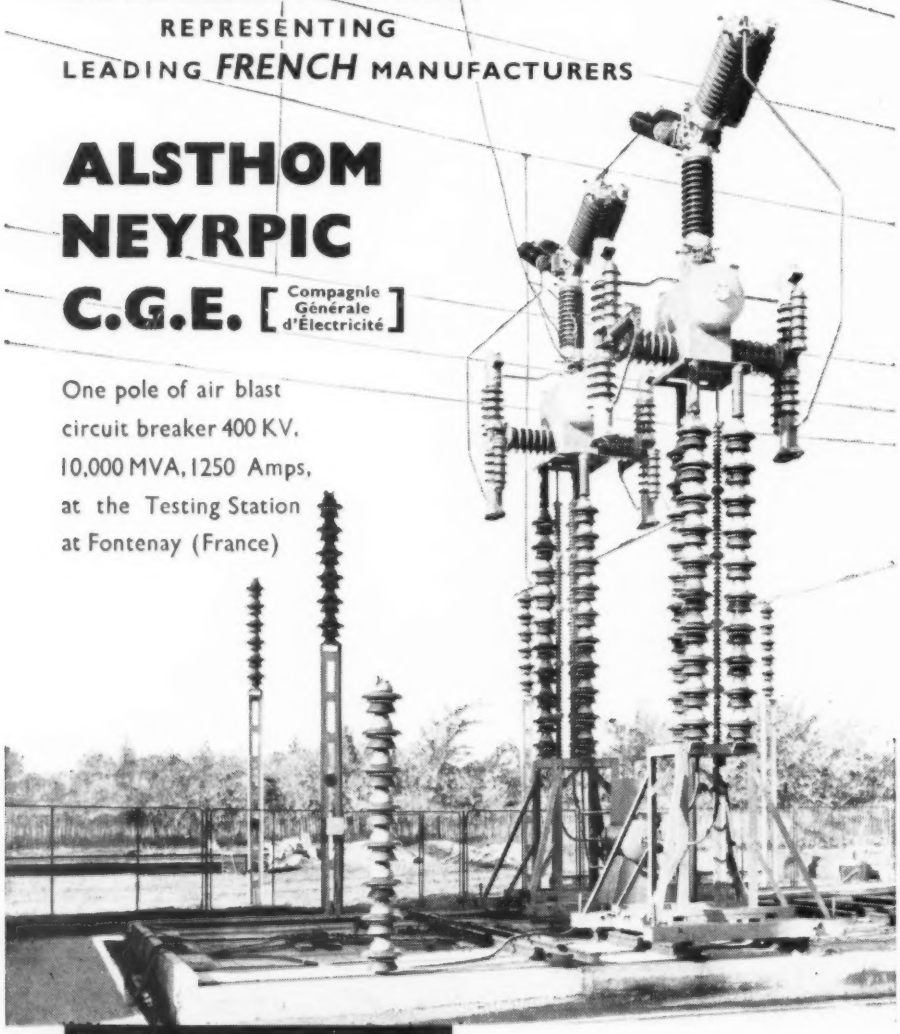

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